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A CBCT study of canalis sinuosus and its accessory canals in patients attending a South African dental hospital

by

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Declaration

I, Michael Andrew Beckenstrater, hereby declare that this thesis entitled, “A CBCT study of canalis sinuosus and its accessory canals in patients attending a South African dental hospital”, which I herewith submit to the University of Pretoria in fulfilment of the requirements of the degree: MSc (Dentistry) is my own original work, and has not been submitted for any academic award or qualification at this or any other institution of higher learning.

____________________ 01/11/2022____________

Signature Date

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Executive summary

The anterior maxilla is a site of frequent surgical intervention during modern dental procedures. Canalis sinuosus (CS) is a lesser-known anatomical structure residing in this region. CS is an intra-osseous canal housing the anterior superior alveolar nerve (ASAN) and artery (ASAA). The terminal portion of CS frequently gives rise to discrete intra-osseous canals, termed accessory canals (AC), which descend to terminate in various anatomical locations. Intra-operative damage to CS or it's ACs may cause post-operative pain and paraesthesia, intra-operative haemorrhage, and failure of osseointegration of dental implants. Accurate knowledge of the anatomy of CS is needed to promote safe clinical practice. This cross-sectional, retrospective study aimed to determine the prevalence and distribution of CS and its ACs in the South African population, as well as describe its anatomical variations.

The present study examined 500 cone-beam computed tomography (CBCT) scans of the anterior maxilla and recorded the prevalence, sidedness, diameter, and distribution of CS. The frequency, number, mean diameter, configuration, and point of termination of the ACs of CS was also determined. Data was collected through means of visual and metric analysis by an investigator calibrated with two experienced dental academics. Statistical analysis was performed using chi-squared or Fisher Exact tests depending on the sample size. Mean values were compared by analyses of variance (ANOVA). Median values were compared by Kruskal-Wallis tests. The level of significance was set at $P = 0.05$.

The findings of the present study agreed with literature stating that CS should be regarded as a distinct anatomical entity. The majority of patients within the present study presented with CS bilaterally (98%). The mean diameter of CS was recorded at 1.08mm. Sex, population group, and age demonstrated no significant effect on the prevalence or sidedness of CS ($P > 0.05$).

The ACs of CS presented as individual entities rather than bilateral pairs. Whilst the majority of subjects presented with at least one AC (58% of subjects), the ACs of CS should be considered anatomical variations, as they displayed highly variable anatomy and inconsistent prevalence. The mean diameter of the ACs in the present study was found to be less than 1.00mm.

In the absence of a prevailing classification system describing the configuration of the ACs of CS, the present study classified these structures into five distinct patterns, namely; straight vertical, curved medially, curved laterally, curved distally, and other. The majority of the ACs found in the present study demonstrated a straight vertical configuration (72%).

The ACs of CS in the present study terminated in five principal regions, namely; palatal, transversal, or buccal of the maxillary teeth, the mid-palatal region, and near the incisive foramen. The majority of ACs (57%) terminated palatal of the maxillary teeth.

Meticulous examination of a high quality CBCT scan prior to surgical intervention of the anterior maxilla is critical to avoid intra-operative damage to CS and its ACs. Clinicians should have a thorough understanding of clinically relevant anatomy and be well-versed in the interpretation of CBCT scans to avoid unnecessary surgical complications.

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Abbreviations

canalis sinuosus = CS

anterior superior alveolar nerve = ASAN

anterior superior alveolar artery = ASAA

posterior superior alveolar artery = PSAA

accessory canals = AC

cone-beam computed tomography = CBCT

posterior superior alveolar nerve = PSAN

infraorbital nerve = ION

infraorbital foramen = IOF

middle superior alveolar nerve = MSAN

middle superior alveolar artery = MSAA

anterior superior alveolar = ASA

confidence interval = CI

standard deviation = SD

cleft lip and palate = CLP

1. Defining the research problem

The anterior maxilla is the site of frequent surgical intervention during the placement of dental implants, orthognathic surgery, endodontic surgery, and the removal of impactions (1–8). Accordingly, intimate knowledge of the anatomy and anatomical variations of this region is paramount to safe clinical practice. A commonly overlooked structure residing in the anterior maxilla is the canalis sinuosus (CS) (2,5). This intra-osseous canal accommodates the anterior superior alveolar neurovascular bundle (9). Although CS is a normal anatomical structure, it, and its anatomical variations, are rarely addressed in anatomical texts and scholarly literature [at the time of writing (October 2022) a PubMed search yielded 39 results for the keywords "canalis sinuosus", 12 of which were case reports].

With the rise of implantology and an increased demand for dental implants in the aesthetic zone, the clinical significance of CS is ever increasing. Reports indicate that damage to CS during surgical intervention may be responsible for paraesthesia of the upper lip, intra-operative haemorrhage, and failure of implant osseointegration (8,10–13).

The prevalence and description of CS and its ACs in the South African population is currently unknown. Knowledge of local anatomy regarding the CS and its variations may improve the pre-operative planning performed by clinicians prior to surgical intervention and therefore decrease the likelihood of iatrogenic damage, as well as, equip the practitioner to appropriately manage intra-operative complications arising from damage to the structure. The present study aimed to describe the prevalence and distribution of CS and its ACs, as well as describe its anatomical variations in a sample of South African patients through the means of retrospective analysis of CBCT scans.

2. Literature review

2.1 Background:

Definition:

Canalis Sinuosus is the bony canal in which the anterior superior alveolar nerve (ASAN) resides (9). The anterior superior alveolar artery (ASAA) typically accompanies the ASAN (9). Wood-Jones first described the canal in 1939 and coined the term *"Canalis Sinuosus"*, owing to its double curved course and sigmoid shape (9).

Origin:

The precise formation, embryological or otherwise, of CS is poorly documented in current literature (14). However, CS lies entirely within the maxilla. Analysis of the embryological formation of the maxilla may provide insight into the formation of the canal.

Jacobs *et al*. explains that the maxilla is a component of the viscerocranium and is of mesenchymal origin (15). It is formed via intramembranous ossification of the first pharyngeal arch (15). Neural crest cells present in the first pharyngeal arch form the maxillary branch of the trigeminal nerve, thus ultimately forming the ASAN (15).

As reported by Rusu *et al.*, the maxilla is formed by two primary ossification centres; where the antero-medial ossification centre forms the pre-maxilla (carrying the incisors), and the postero-lateral ossification centre forms the maxilla proper (14). The second angle of CS resides at the junction between the pre-maxillary and maxillary ossification centres, while the first angle of CS is located in close approximation to the postero-lateral ossification centre (14). The pre-maxillary and maxillary ossification centres fuse rapidly in the area of the future canine alveolus and leave almost no evidence of a true suture (14). This region is referred to as the "incisive suture" (14). Wood-Jones stated; "*The incisive suture should not be regarded as a true suture because it does not completely separate the upper jaw into anterior and posterior bones at any stage of development in the normal human embryo*" (9). However, in 2001, through the use of histological and radiographic evaluation, Vacher *et al.* determined the nature of the incisive suture to be that of a true facial suture with notably reduced vascularisation (16). Therefore, the previous statement of Wood-Jones has been proven to be inaccurate (9,16).

Course:

The course of CS is well documented with multiple sources describing its path (1,2,9,13,14,17,18). At least three different methods of investigation describing the course of CS are reported in current literature. The most common technique is the retrospective analysis of existing cone beam computed tomography (CBCT) scans with slice thicknesses varying between 0.5 – 10mm (1,2,14,19). The two other methods include the dissection of fresh cadaver heads and macerated skulls (17,18).

The studies which analysed the course of CS using CBCT scans included those of; Wanzeler *et al.*, Gurler *et al.*, and Rusu *et al.* (1,2,14). Dissection of fresh cadaver heads was carried out by Von Arx & Lozanoff (17), while Olenczak *et al.* performed dissections on macerated skulls and CBCT analysis (18).

Sedov *et al.* investigated the effect of CBCT slice thickness on the detection and visualisation of CS in the Russian population (20). The study retrospectively analysed 100 CBCT scans at slice thicknesses of 0.5mm, 1.0mm, 3.0mm, and 10.0mm respectively (20). Sedov *et al.* reported that the thinner the slice thickness the greater the incidence of CS detection, with the incidence of detection at 0.5 and 1.0mm being the same (20). The study concluded that a slice thickness of 0.5/1.0mm is optimal for the visualisation of CS (20). This conclusion was supported by another Russian study conducted by Anatoly *et al.* who, as part of the methodology of a greater study, repeated the same intervention as Sedov *et al.* (19,20).

The literature widely agrees that CS resembles a sigmoid shape maintaining a double curved appearance (1,2,9,14,17,18). CS resides entirely within the maxilla and originates from the infraorbital canal posterior to the infraorbital foramen (1,2,9,14,17,18). From this point of origin, the canal progresses antero-laterally towards the anterior wall of the maxilla (1,2,9,14,17,18). After reaching the anterior wall of the maxilla the canal turns medially to cross the anterior antral wall running lateral to medial (1,2,9,14,17,18). The canal maintains a horizontal path as it runs medially towards the nasal aperture. This section runs at a level inferior to the infraorbital foramen (1,2,9,14,17,18). As the canal approaches the nasal aperture it curves 90˚ to descend parallel to the lateral wall of the nasal aperture (1,2,9,14,17,18). Once the canal reaches the most inferior aspect of the lateral border of the nasal aperture it turns medially to follow the floor of the nasal aperture before terminating adjacent to the nasal septum anterior to the incisive canal (1,2,9,14,17,18). After this point the canal commonly presents with anatomical variations, termed accessory canals (AC), which frequently terminate in the anterior palatal region (1,2,9,14,17,18). Figure 1 provides a visual representation of the course of CS.

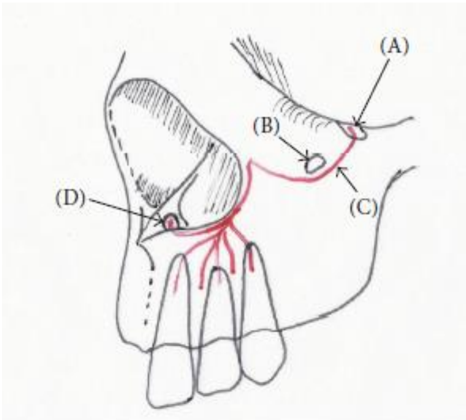

Figure 1: Schematic illustration of the rudimentary course of CS in the maxilla (13). Anatomical landmarks include: (A) inferior orbital groove, (B) Inferior orbital foramen, (C) Course of CS, (D) Foramen septale, a bilateral structure at the nasal spine.

In 2015 Von Arx & Lozanoff morphometrically assessed the precise relation of CS and the ASAN relative to the infraorbital canal and piriform aperture through the means of a digital calliper and the dissection of 10 skull hemi-sections taken from five fresh cadaver heads (17). The soft tissue overlying the hemi-sections was removed following which the skulls were placed in a solution of rapid bone decalcifier for 16 hours. The bone overlying CS was then removed to reveal the course of the ASAN (17).

The study found that CS originated on average 12.2mm [Standard Deviation (SD) ±5.79mm] posterior to the infraorbital foramen with six cases branching laterally and four cases branching inferiorly from the infraorbital canal (17). After the canal's anterior-lateral course it was located on average 2.8mm (±5.13mm) lateral to the infraorbital foramen (17). On average the canal ran 5.5mm (±3.07mm) below the infraorbital foramen as it transversed the anterior antral wall (17). Before the canal begins its descent parallel to the nasal aperture it is typically located 13.6mm

(±3.07mm) above the nasal floor (17). During its descent the canal was found to be 4.3mm (±2.64mm) and 3.3mm (±2.60mm) lateral to the nasal aperture at its midpoint and at the floor of the nose respectively (17). These findings are illustrated in figure 2.

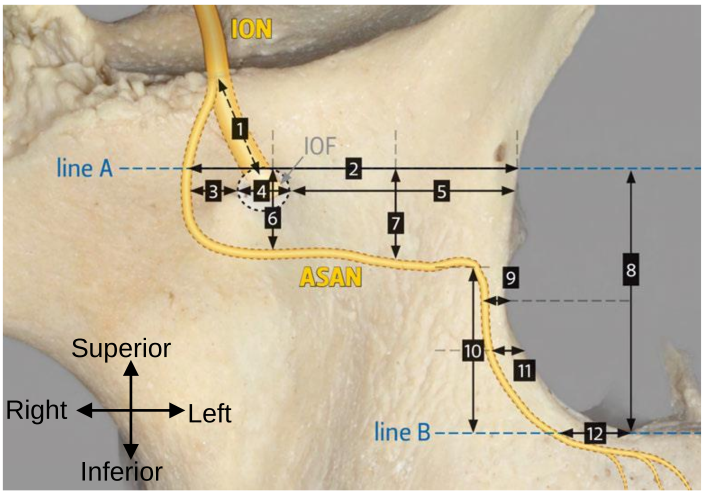

Figure 2: Schematic illustration of the measured course of CS. The illustration depicts the measurements taken by Von Arx & Lozanoff which compared the course of CS in the maxilla relative to other anatomical landmarks (17). The following abbreviations are used; Infraorbital nerve (ION), Infraorbital foramen (IOF), Anterior superior alveolar nerve (ASAN).

Olenczak *et al.* performed a similar study by dissecting 12 cadaver heads and analysing 50 CBCT scans (1mm slice thickness) to determine the course and dimensions of CS (18). The study determined that CS originated 18mm posterior to the infraorbital rim (18). Furthermore, the study determined that CS maintained a 12.9mm (±2.2mm) horizontal course in the anterior maxilla, while measuring a vertical length of 11.7mm (±3.0mm) along the piriform aperture (18).

A study conducted by Rusu *et al.* in 2020 evaluated 300 CBCT scans of the area previously occupied by the incisive suture among adults (14). The study confirmed the course of CS as described by Wood-Jones, and von Arx & Lozanoff (9,17), however the study added that CS also communicated with the canal of Parinaud. Parinaud's canal is an intra-osseous canal which originates from Macalister's foramina (14). The canal of Parinaud resides in the region of the incisive suture and courses parallel to the nasal aperture in a vertical direction (14). The canal is depicted in the image below (14). Wood-Jones unknowingly described this connection between the two canals during his documentation of the course of CS (9). Rusu *et al.* established that the medial aspect of the descending portion of CS, which runs parallel to the nasal aperture, communicates with the canal of Parinaud (14). The communication between CS and Parinaud's canal is illustrated in figure 3.

Figure 3: Rusu et al.'s 3D renderings of the anterior view of the midface. The renderings illustrate CS (white arrow heads), canals of Parinaud (black arrow heads), and infraorbital canals (white arrows). A left accessory infraorbital canal is indicated by the black arrow (14).

Due to limitations in radiology Rusu *et al.* could not determine the contents of the canal of Parinaud (14). However, the study suggested that the canal contents may be neurovascular in nature (14). The article further hypothesised that the contents of the canal of Parinaud could be; the nasal branch of the infraorbital artery, or an intra-osseous variant of the angular artery (terminal branch of the facial artery) which may anastomose with minute branches of the ASAA (14). Wood-Jones stated: "*The canal appears to be entirely vascular, no branch of the nerve having been traced to it*" (9). Rusu *et al.* recommended histological sampling of the canal of Parinaud to determine the true nature of its contents (14).

Contents:

As stated previously CS is the bony counterpart to the ASAN which is followed by the ASAA (9).

The ASAN stems from the infraorbital nerve, which is in turn a branch of the maxillary branch of the trigeminal nerve (21). The dissection by Von Arx & Lozanoff demonstrated that the ASAN consists of a single nerve trunk containing between two and four fascicles (17). Gray documented that the ASAN provides innervation to; the central and lateral incisor, canine, and the surrounding soft tissue including the upper lip and oral mucosa (21). Furthermore, the ASAN gives off a small nasal branch which innervates the mucous membrane of the anterior part of the inferior meatus and floor of the nasal cavity (21). Gray furthermore noted that the ASAN gives off a small but distinct posterior loop which communicates with the middle superior alveolar nerve

(21). However, studies show the middle superior alveolar nerve (MSAN) is inconsistent, with the nerve reportedly absent in 18 – 77% of cases (22–24). In such cases the innervation of the premolars and mesio-buccal root of the first molar stems from the posterior superior alveolar nerve (PSAN) and ASAN (22).

The ASAA stems from the maxillary artery which is a branch of the external carotid artery (25). The ASAA supplies the central and lateral incisor, canine, and the mucous membrane of the maxillary sinus (25). Another consistent finding of Von Arx & Lozanoff was the anastomoses between the posterior superior alveolar artery (PSAA) and the ASAA (17).

2.2 Prevalence of canalis sinuosus

Due to limited anatomical knowledge (1) and poor recognition of CS by health care professionals (2,10) early literature debated as to whether CS existed as an anatomical anomaly or as a distinct anatomical entity.

Wanzeler *et al.* examined 100 CBCT scans of the maxilla in the Brazilian population and observed the presence of CS in 88% of subjects (1). The study recorded a single instance of the unilateral distribution of CS, with all other cases (*n* = 87/88) presented bilaterally (1). Ghandourah *et al.* examined 219 CBCT scans of the midface in the German population and reported bilateral existence of CS in 100% of the sample population (26). Gurler *et al.* assessed 111 CBCT scans of patients with impacted maxillary canines and observed the bilateral presence of CS in all cases (*n* = 111/111; 100%) within the Turkish population (2). Therefore, the conclusion of Wanzeler *et al.*; that CS is indeed a distinct anatomical structure and not merely an anatomical variation, is strongly supported by the studies of Ghandourah *et al.* and Gurler *et al.* (1,2,26).

Aoki *et al.* studied 200 CBCT scans of the maxilla in the Brazilian population and observed CS in 66.5% (*n* = 133/200) of cases, with 54% (*n* = 72/133) occurring bilaterally and 46% (*n* = 61/133) occurring unilaterally (27). Similarly, Anatoly *et al.* evaluated 150 CBCT scans of the maxilla in the Russian population and reported CS in 67% (*n* = 101/150) of cases, with 46% (*n* = 47/101) occurring bilaterally and 54% (*n*

= 55/101) occurring unilaterally (19). Yeap *et al.* evaluated 201 CBCT scans of the maxilla in the Australian population and found CS in 98.5% (*n* = 198/201) of cases (28). Accordingly, with the majority of cases demonstrating the presence of CS at 66.5%, 67%, and 98.5% respectively, Aoki *et al.*, Anatoly *et al.*, and Yeap *et al.* also concluded that CS can be considered a distinct anatomical structure (19,27,28).

It is important to note that in the studies of Aoki *et al.*, Anatoly *et al.*, and Yeap *et al.*, no distinction was made between CS and its ACs, but rather the entire structure, including ACs, was considered as a single entity when recording prevalence of CS (19,27,28). Therefore, if no ACs were detected the entire structure was considered absent (19,27,28). Furthermore, the studies did not use the term 'AC' and reported all findings under the term 'CS' (19,27,28). This may explain the lower prevalence of CS recorded in the studies of Aoki *et al.* and Anatoly *et al.* at 66.5% and 67% respectively (19,27), when compared to the studies of Wanzeler *et al.*, Ghandourah *et al.*, and Gurler *et al.* at 88%, 100%, and 100% respectively (1,2,26).

The prevalence of CS varies between 66.5% and 100% across different population groups (1,2,19,26,27). The literature indicates that CS exists as a distinct anatomical entity with the majority of study subjects possessing at least one CS (1,2,19,26,27). The variation in prevalence of CS may be attributed to fundamental differences present between different populations groups (genetic or environmental), or differences in study design (minimum CBCT slice thickness, voxel size, or minimum canal diameter) (1,2,19,26,27). Table 1 summarises the findings of previous studies investigating the prevalence of CS.

Table 1: **Summary of results of studies investigating the prevalence of CS.**

Study	Sample size (n)	Population	Prevalence (%)	Bilateral cases (%)	Unilateral cases (%)
Wanzeler et al. (1)	100	Brazilian	88/100 (88.0)	87/88 (99.0)	1/88 (1.0)
Ghandourah et al. (26)	219	German	219/219 (100.0)	219/219 (100.0)	0/219 (0.0)
*Gurler et al. (2)	111	Turkish	111/111 (100.0)	111/111 (100.0)	0/111 (0.0)
Aoki et al. (27)	200	Brazilian	133/200 (66.5)	72/133 (54.1)	61/133 (45.9)
Anatoly et al. (19)	150	Russian	101/150 (67.3)	47/101 (46.5)	55/101 (54.5)
Yeap *et al.* (28)	201	Australian	198/201 (98.5)	Not stated	Not stated

*Gurler et al. exclusively investigated cases with impacted maxillary canines (2).

2.2.1 Prevalence in South Africa

To date no study exists surrounding the prevalence of CS or its ACs in the South African population. The only African study to investigate CS was conducted in the Egyptian population by Marzook *et al.*, thus representing a different population to the local South African population (29). The significant geographical separation between these two population groups may result in significant differences in ethnic and genetic factors influencing the prevalence, structure, distribution of CS and its variations.

2.3 Bony canals in the anterior maxilla

While most dentists are well acquainted with the nasopalatine canal and incisive foramen, the recent increase in surgical intervention performed in the anterior maxillary region requires a more intimate knowledge of all the anatomical structures residing in this region (2–4,29). Studies by Oliveira-Santos *et al.*, Von Arx *et al.*, and Marzook *et al.* aimed to address this deficit in knowledge by investigating the presence of minor ACs and foramina in the anterior maxilla (3,4,29).

In 2012 Oliveira-Santos *et al.* retrospectively analysed 178 CBCT scans of the anterior maxilla in the Belgian population for the presence of any intra-osseous canal with a minimum diameter of 1.0mm other than the nasopalatine canal. In their study, 15.7% of subjects (*n* = 28/178) presented with at least one accessory bony canal, with a total of 34 ACs recorded (3). The mean diameter of the AC's foramina was 1.4mm with a range of 1.0–1.9mm (3).

Oliveira-Santos *et al.* discovered three distinct patterns of origin among the ACs (3). The most common pattern (*n* = 18/34; 52.9%) did not directly communicate with CS, but rather originated from the medial aspect of the floor of the nasal aperture (3). The second pattern (*n* = 14/34; 41.2%) communicated directly with CS and curved inferiorly towards the alveolar bone (3). Finally, in two cases (5.9%) a bony canal originated from the nasopalatine canal superiorly and diverged to exit adjacent to the incisive foramen (3). The study did not link the position of the bony foramen to the canal's point of origin.

A near identical study was conducted in 2013 by Von Arx *et al.* in the Swiss population (4). Von Arx *et al.* retrospectively examined 176 CBCT scans (0.5mm slice thickness) of the anterior maxilla for the presence of any bony canal with a minimum diameter of 1.0mm other than the nasopalatine canal (4). In their study 27.8% of subjects (*n* = 49/176) presented with at least one accessory bony canal, with a total of 67 ACs observed (4). The ACs averaged a diameter of 1.3mm (±0.3mm) with a range of 1.01–2.1mm (4). Von Arx *et al.* also recorded the prevalence of ACs where no minimum diameter was imposed showing a notable increase in prevalence to 55.1% (4). However, the remainder of the study exclusively dealt with canals greater than 1.0mm in diameter (4).

Intriguingly, Von Arx *et al.* also discovered three distinct patterns of origin among the ACs (4). The most common pattern (*n* = 38/67; 56.7%) communicated directly with CS and curved inferiorly towards the alveolar bone, terminating palatal to the lateral incisors and canines (4). The second pattern (*n* = 26/67; 38.8%) did not directly communicate with CS, but rather originated from the medial aspect of the floor of the nasal aperture (4). These ACs then projected vertically towards the anterior palate, most commonly terminating palatal to the central incisors (4). Finally, in three cases (4.5%) a 'Y-shaped' pattern emerged with one branch originating from CS and the other originating from the medial aspect of the nasal aperture (4). This pattern also terminated palatal to the central incisors (4). These three patterns of configuration of the ACs are illustrated in figure 4.

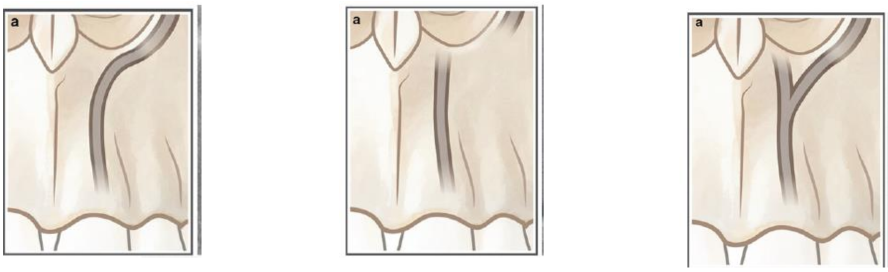

Figure 4: Schematic illustration of the three variations of ACs in the anterior maxilla described by Von Arx et al. (4)*. Reproduced with permission from Springer-Verlag France publishers.*

It is interesting to note that despite the geographical separation of the two population samples both Oliveira-Santos *et al.* and Von Arx *et al.* recorded two identical patterns of the origin of the ACs (3,4). The first pattern originating directly from CS, and the second from the medial aspect of the floor of the nasal aperture (3,4).

Oliveira-Santos *et al.* and Von Arx *et al.* agreed that the ACs which communicated directly with CS most likely contained direct extensions of the ASA nerve and artery (3,4). Oliveira-Santos *et al.* proposed that the ACs which originated from the medial aspect of the floor of the nasal aperture may represent accessory branches of the nasopalatine nerve (3), while Von Arx *et al.* did not comment on their potential contents (4). Oliveira-Santos *et al.* further alluded to the possibility of these canals containing an extension of the ASA nerve/artery due to its proximity to the terminal portion of CS (3). Furthermore, Oliveira-Santos *et al.* proposed that in both cases, with and without accessory bony canals, anastomosis may exist between the ASA and nasopalatine neurovascular bundles (3). Von Arx *et al.* did not comment on the potential contents of the 'Y-shaped' pattern observed in their study (4). While Oliveira-Santos *et al.* proposed that the ACs diverging from the nasopalatine canal contained branches of the nasopalatine neurovascular bundle (3). While Oliveira-Santos *et al.* and Von Arx *et al.* provide reasonable theories as to the contents of the ACs their theories remain speculation (3,4).

In 2020 Marzook *et al.* retrospectively analysed 170 CBCT scans of the skull in the Egyptian population to identify any accessory foramina or canals present in the hard palate other than the nasopalatine, greater palatine and lesser palatine canals (29). Hence this study differs from the previous studies by Oliveira-Santos *et al.* and Von Arx *et al.* (3,4), as the study by Marzook *et al.* examined the entire hard palate rather than merely the anterior maxilla (29). Furthermore, the study by Marzook *et al.* did not employ a minimum diameter to detect foramina/ canals (29). Consequently, 78.2% of subjects (n = 133/170) recorded at least one AC, with 73.5% of subjects (n = 125/170) possessing an AC originating directly from CS (29). A higher incidence of ACs stemming from CS was expected in this study due to the absence of a minimum inclusion diameter.

A peculiar finding of Marzook *et al.* was the discovery of foramina located in the posterior aspect of the palate which originated from CS (29). The prevalence of this finding was not reported, however, images are available (29). Different branching patterns of the ACs of CS were recorded by Marzook *et al.*, including; palatal, dental, and labial branches, as well as, high and low anterior and posterior branches (29). However, the study of Marzook *et al.* was poorly described and this questions the reliability and validity of the study (29).

The studies investigating ACs in the anterior maxilla conducted by Oliveira-Santos *et al.*, Von Arx *et al.*, and Marzook *et al.* all demonstrate at least one pattern of ACs which communicate directly with CS (3,4,29). The incidence of ACs in the anterior maxilla differ significantly between studies ranging between 15.7% – 78.3% (3,4,29). Thus the literature indicates that the anterior maxilla is replete with minor intra-osseous canals which may, or may not, represent direct extensions of CS (3,4,29).

2.4 Accessory canals of canalis sinuosus

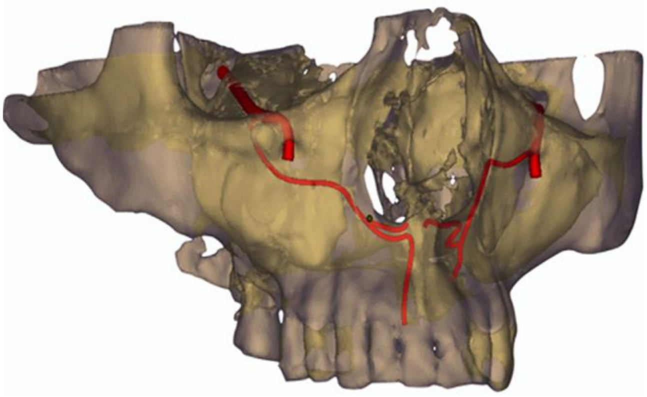

Figure 5: Machado et al.'s 3D rendition of the midface highlighting the course of CS giving off two ACs bilaterally (6)*. Reproduced with permission from Elsevier publishers.*

2.4.1 Global prevalence, variation, and termination of the accessory canals of canalis sinuosus

As literature established that CS is a normal anatomical entity, and multiple ACs reside within the anterior maxilla, the attention of the academic community turned towards the study of the ACs of CS. Several studies show that the terminal portion of CS frequently gives rise to discrete intra-osseous canals which descend to terminate in various anatomical locations, most commonly the anterior palate (3–7,19,26,27,29–31). For a bony canal present in the anterior maxilla to classify as an AC of CS the canal must originate as a direct, intra-osseous, extension of CS (3–7,19,26,27,29–31). For ease of reference several authors refer to the anterior palate as extending to the distal aspect of the first premolar (5–7,26).

To date the largest study assessing the ACs of CS was conducted in 2017 by Orhan *et al.* who examined 1460 CBCT scans of the maxilla within the Turkish population (5). Orhan *et al.* discovered at least one AC (representing a direct extension of CS) in 70.8% of all cases (*n* = 1034/1460), recording a total of 6668 ACs (5). The study investigated any AC present in the vicinity of CS measuring "*approximately 1mm*" in diameter. The study did not investigate the average diameter of the ACs (5).

The study by Orhan *et al.* determined that in isolation ACs most frequently terminated in the interdental region between the central incisors (5). However, when bilateral locations were considered the most common region of termination occurred near the central incisors, followed by the lateral incisors and then the canines representing 19.4%*, 19.0%*, and 17.8%* of all ACs respectively (5). The study found the lowest number of ACs terminating in the interproximal region of the canines and first premolars representing only 2.6%* of all ACs (5). Orhan *et al.* further noted that 12.2%* of ACs terminated around the incisive foramen, exiting either anterior, posterior, or immediately lateral to the incisive foramen (5). The relatively low incidence of ACs recorded at each region of termination could be attributed to the higher number of anatomical locations, and thus greater detail, recorded by Orhan *et al.* (5) when compared to other studies.

A similarly large study assessing the ACs of CS was conducted in 2016 by Machado *et al.* who retrospectively examined 1000 CBCT scans of the anterior maxilla within the Brazilian population (6). Machado *et al.* found that 52.1% of subjects (n = 521/1000) presented with at least one AC of CS, detecting a total of 974 ACs (6). Machado *et al.* observed as many as seven ACs of CS in a single patient (6). The majority of ACs terminated palatal to the maxillary teeth (n = 887/974; 91.1%), with a minor portion terminating in a buccal (n = 50/974; 5.1%) or a transversal (n = 37/974; 3.8%) position (6). This finding is significant as only the studies by Marzook *et al.* and Anatoly *et al.* also recorded the buccal or transversal termination of ACs (19,29). It is unclear whether this is due to increased precision in spatial definition given by Machado *et al.*, or whether other sample populations did not present with ACs in buccal or transversal positions.

In 2020 Shan *et al.* retrospectively analysed 1007 CBCT scans of the maxilla in the Chinese population to identify ACs of CS with a minimum diameter of 1.0mm (30). Shan *et al.* observed ACs of CS in 36.9% (n = 372/1007) of cases (30). The study demonstrated a positive correlation between the anterior maxillary volume and the prevalence of ACs (30). Furthermore, the study observed that all the ACs of CS terminated in the anterior hard palate with the most common position of exit occurring in the region between the central and lateral incisors, representing 61.9% of all ACs

* *Note; the percentages indicated in the paragraph addressing the study by Orhan et al .*(5) *are not taken directly from the study but rather reported following the interpretation of the study's table of results.*

(30). The study also reported that the ACs exited the anterior palate on average 5.7mm (±2.4mm) away from the palatal alveolar crest (30).

A 2021 study by Şalli & Öztürkmen retrospectively examined 673 CBCT scans of the anterior maxilla to assess the prevalence of ACs of CS with a diameter of approximately 1mm among the Turkish population (31). Şalli & Öztürkmen reported that 8.2% of patients presented with at least one AC of CS (*n* = 55/673), recording a total of 62 ACs (31). ACs most commonly terminated in the anterior palatal region of the lateral incisors representing 25.8% of all ACs (31).

In 2019 Tomrukçu & Köse retrospectively examined 326 CBCT scans of the maxilla in the Turkish population to assess the prevalence and characteristics of the ACs of CS (7). Tomrukçu & Köse observed ACs of CS in 34.7% of cases (*n* = 113/326), recording a total of 214 ACs (7). Tomrukçu & Köse (7)further classified these ACs into three principal configurations; curved, vertical, and 'Y-shaped' (7). The curved configuration was most common representing 69.2% of the ACs of CS. While 26.2% of the ACs occupied a vertical configuration and the remaining 4.7% demonstrated a 'Y-shaped' configuration (7). This finding is reflective of the findings of Von Arx *et al.* (4). However, it is important to note that Von Arx *et al.* stated that the vertical pattern of the ACs did not communicate with CS (4).

Unlike Von Arx *et al.*, Tomrukçu & Köse did not correlate the terminal position of the ACs with the general configuration of the canal (4,7). However, Tomrukçu & Köse recorded that all the ACs of CS terminated in the anterior palate with the most common position of termination occurring palatal of the lateral incisors representing 31.8% of ACs (7). While 23.8% of the ACs terminated palatal of the central incisors, and 13.2% terminated palatal of the canines (7). The remaining canals terminated at various positions between the junction of two anterior teeth or in the region of the premolars (7).

In 2017 Ghandourah *et al.* examined 201 CBCT scans (1mm slice thickness) of the midface in the adult German population to identify ACs of CS measuring greater than 0.5mm in diameter in the anterior maxilla (26). The study found at least one AC communicating directly with CS in 67.6% of cases (*n* = 136/201), detecting 285 ACs in total (26). ACs with a diameter greater than 1mm were detected in 27.4% (*n* = 55/201) of cases (26). These findings are similar to the findings of Von Arx *et al.* (4).

Ghandourah *et al.* identified five chief points of exit of the ACs into the anterior palate (26). The most common point of exit, representing 41.3% of cases, was found in the region of the central incisor (26). This was followed by 31.3% of cases which exited near the lateral incisors and 27.4% which exited near the canines (26). A minority of cases exited in the regions of left and right premolars with 5.5% and 3.6% respectively (26). Ghandourah *et al.* also analysed 18 CBCT scans of the midface among the adolescent German population – however these findings are not discussed in this literature review, as a sample size of 18 was inadequate for statistical analysis (26).

Yeap *et al.* retrospectively examined 201 CBCT scans of the maxilla in the Australian population to assess the characteristics of CS (28). Yeap *et al.* found that 98.5% (*n* = 198/201) of cases possessed at least one instance of CS, all of which terminated in an AC (28). The majority of ACs terminated in the anterior palate (81.8%) with the most common point of termination occurring palatal of the central incisors (41.3%). While 35.2% of the ACs terminated palatal of the lateral incisors, and 5.3% terminated palatal of the canines (28). Only one percent of ACs terminated on the labial aspect of the maxilla (28).

In 2019 Aoki *et al.* studied 200 CBCT scans of the maxilla in the Brazilian population to analyse the terminal trajectory of the canal (27). Aoki *et al.* determined 66.5% (*n* = 113/200) of cases to possess CS, of these every case terminated in an AC (27). Aoki *et al.* reported that 92.7% of all canals terminated in the anterior palate, with the most frequent point of termination occurring in the region of the central incisors (*n* = 91/205; 44.4%), followed by lateral incisors (*n* = 45/205; 21.95%), the canines (*n* = 29/205; 14.2%), and finally the junction between the central and lateral incisors representing 12.2% (*n* = 25/205) of all ACs (27). The remaining 7.3% of ACs (*n* = 15/205) terminated by joining the nasopalatine canal (27).

In 2019 Anatoly *et al.* evaluated 150 CBCT scans of the maxilla to determine the morphological characteristics of CS and its ACs in the Russian population (19). The study determined 67% (*n* = 101/150) of cases to possess CS, all of which terminated in an AC. Anatoly et al. recorded the lateral incisor region as the most frequent location (*n* = 50/149; 33.5%) for termination of the ACs of CS (19). The regions of the central incisor and canine followed with 24.5% (*n* = 36/149) and 21.5% (*n* = 32/149) respectively (19). Interestingly, while the majority of the ACs (*n* = 113/149; 76%)

terminated in the palatal region (19). Anatoly *et al.* further detailed that 18 cases (12%) terminated facially, and another 18 cases (12%) exited centrally (19). Although not described in the text ACs which terminated "*centrally*" were presumed to terminate on the crest of the alveolar ridge i.e.; at the interface between the palatal and facial surfaces of the anterior maxilla. Unlike Oliveira-Santos *et al.* and Machado *et al.*, Anatoly *et al.* did not develop a diagram of the foramina of the ACs of CS which would improve the ease with which the study's results may be interpreted (3,6,19).

In 2022 Beyzade *et al.* retrospectively examined 91 CBCT scans of the maxilla in the Cypriot population to assess the clinical implications of ACs of CS (32). Beyzade *et al.* recorded ACs of CS in all (*n* = 91/91; 100%) cases (32). The study found a total of 188 ACs with 94.5% of cases presenting bilaterally (*n* = 86/91) and the remaining 5.5% (*n* = 5/91) of cases presenting unilaterally (32). The most common region of termination occurred palatally of the lateral incisors accounting for 46.8% (*n* = 88/188) of cases (32). No cases of buccal termination of the ACs were recorded in the study (32).

It is important to note that the findings of Aoki *et al.*, and Anatoly *et al.* were reported under the term 'CS' and not as AC of CS (19,27). However, when assessing the methodology of these studies it was seen that the studies investigated the ACs as described above.

The literature indicates that the prevalence of ACs of CS varies substantially between sample populations ranging between 8.17 – 100% (5–7,19,26–28,30–32). The apparent prevalence of the ACs of CS was influenced by the prescribed minimum diameter to register a canal, with a higher prevalence recorded at 0.5mm than 1.0mm (4,26,30,31). The majority of ACs terminated in the region of the anterior palate (5–7,19,26–28,30–32). ACs were also found to terminate in buccal/facial and transversal positions of the maxilla (6,19,28). The studies by Orhan *et al.*, Ghandourah *et al.*, Yeap *et al.*, and Aoki *et al.* were in agreement of the finding that the most common position of termination for the ACs was in the region of the central incisors (5,26–28). While Machado et al., Şalli & Öztürkmen, Tomrukçu & Köse, Anatoly *et al.*, and Beyzade *et al.* indicated that the region of the lateral incisors was the most common point of termination (6,7,19,31,32). Table 2 summarises the findings of previous studies investigating the prevalence of ACs of the CS and their most common point of termination.

Table 2: **Summary of the prevalence of ACs of CS and their most common point of termination.**

Study	Population	Sample size (*n*)	Minimum detection diameter (mm)	Prevalence of AC of CS (%)	Most common point of termination
Orhan et al. (5)	Turkish	1460	±1.0	70.8	Anterior palate; Interproximal region between the central incisors
Machado et al. (6)	Brazilian	1000	None	52.1	Palatal to the maxillary teeth (91.1%). Posterior to the lateral incisors (27.7%)
Shan et al. (30)	Chinese	1007	1.0	36.9	Anterior palate; between the central and lateral incisors (61.9%)
Şalli & Öztürkmen (31)	Turkish	673	±1.0	8.2	Anterior palate; posterior to the lateral incisors (25.8%)
Tomrukçu & Köse (7)	Turkish	326	Not stipulated	34.7	Anterior palate; posterior to the lateral incisors (31.8%)
Ghandourah et al. (26)	German	201	0.5	67.6	Anterior palate: near the central incisors (41.3%)
Yeap *et al.* (28)	Australian	201 (*198)	None	98.5 (*100)	Anterior palate near the central incisors (41.3%)
Aoki et al. (27)	Brazilian	200 (*113)	Not stipulated	66.5 (*100)	Anterior palate: near the central incisors (44.4%)
Anatoly et al. (19)	Russian	150 (*101)	Not stipulated	67 (*100)	Anterior palate: near the lateral incisors (33.5%)
Beyzade *et al.* (32)	Cypriot	91	None	100	Anterior palate near the lateral incisors (46.8%)

*Exclusively refers to confirmed instances of CS as the studies defined CS as a single entity including ACs.

2.4.2 General patterns of accessory canals & points of termination

The literature depicts three primary regions of termination of the ACs of CS. Machado *et al.* developed a comprehensive diagram to illustrate these various termination points illustrated in figure 6 (6). A brief overview is provided below:

1. Buccal: ACs run to exit on the facial aspect of the maxilla, i.e.; buccal of the maxillary teeth.
2. Transversal: ACs run to exit along the crest of the alveolar bone, i.e.; at the junction of the buccal and palatal surfaces of the maxilla.
3. Palatal: ACs run to exit in the hard palate, i.e.; palatal of the maxillary teeth. This region of termination is by far the most prevalent and records five major subcategories with ACs exiting in close approximation to the following structures;
    a. Central incisors
    b. Lateral incisors
    c. Canines
    d. First premolars
    e. Incisive foramen (posterior, anterior, lateral)

   ACs may terminate at the interdental region between any of the above-mentioned maxillary teeth.

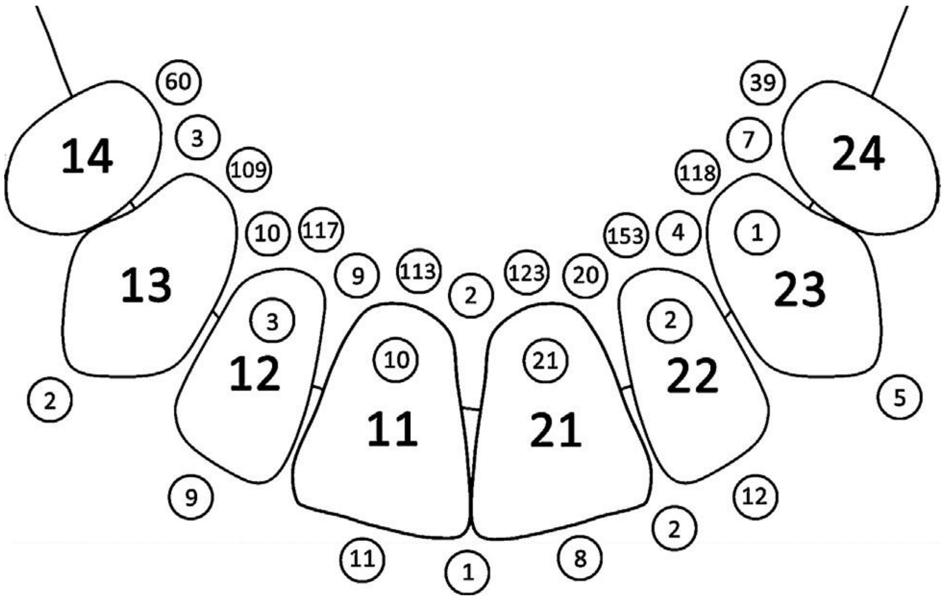

Figure 6: Diagram depicting the local termination of the ACs of CS developed by Machado et al. which illustrates the various exit points of the ACs of CS and the respective number of canals exiting at each point (6)*. Reproduced with permission from Elsevier publishers.*

2.4.3 Diameter of accessory canals

According to Ferlin *et al.'s s*ystematic review the average diameter of CS is accepted to be approximately 1mm with most studies investigating the diameter of ACs (8). Gurler *et al.* determined the mean diameter of CS to be 1.37mm with a range of 0.75 – 2.25mm (2).

Machado *et al.* found that only 20% of all recorded ACs of CS possessed a diameter wider than 1.0mm, with the average diameter of these canals measuring 1.19mm (±0.22mm) with a range of 1.00 – 2.58mm (6). Shan *et al.* also implemented a minimum measurement diameter of 1.0mm and recorded an average canal diameter of 1.1mm (±0.1mm, range; 1.0 – 2.1mm) across all subjects (30). However, Aoki *et al.* found that only 3.4% (*n* = 7/205) of ACs measured a diameter greater than 1mm, while 96.6% (*n* = 198/205) of the ACs measured a diameter of 1mm or below (27). Aoki *et al.* found the diameter of the ACs to be consistent with that of CS, although this measurement was not provided by the study (27).

Beyzade *et al.* found that 89.9% (*n* = 169/188) of the recorded ACs of CS presented with a diameter smaller than 1mm, while a minority of ACs (*n* = 19/188; 10.1%) presented with a diameter larger than 1mm (32). The largest AC recorded measured 2.79mm in diameter (32). However, the study did not record the mean diameter of the ACs.

A study conducted by Tomrukçu & Köse demonstrated that 80.4% (*n* = 172/214) of the ACs of CS displayed a foramen greater than 0.5mm in diameter, while the remaining 19.6% (*n* = 42/214) displayed a foramen smaller than 0.5mm in diameter (7). The mean diameter of the 172 foramina measuring greater than 0.5mm was 1.30mm (±0.44mm; range; 0.57 – 2.88mm), while the mean canal diameter was 1.07mm (±0.35mm) with a range of 0.53 – 2.72mm (7). These measurements lie in accordance with an observation made by Von Arx *et al.* who identified that the foramen of an AC may measure wider than the internal width of the AC (4).

Shan *et al.* and Tomrukçu & Köse reported that the average diameter of the ACs was significantly larger among males than females (7,30). Shan *et al.* reported the average AC diameter to be 1.2mm (±0.1mm) among males and 1.1mm (±0.1mm) among females (30). While Tomrukçu & Köse did not provide the measurements of this finding (7).

Yeap *et al.* extensively investigated the diameter of CS, but did not distinguish between CS and its ACs (28). Accordingly, Yeap *et al.* reported all findings under the term 'CS' (28). Yeap *et al.* took two independent measurements of CS on a single axial slice measuring the widest and narrowest diameters of the canal (28). The study did not employ a minimum detection diameter and measured all canals identified as CS (28). The canal's diameter was measured at a point within the canal in line with the apex of the nearest tooth root, thus these measurements are likely to represent that of ACs rather than CS itself. However, this cannot be said with certainty. Yeap *et al.* determined the mean widest diameter of CS to be 1.08mm and the mean narrowest diameter to be 0.71mm, thus demonstrating the oval nature of CS (28). No average diameter was calculated in the study.

Oliveira-Santos *et al.* and Von Arx *et al.* broadly investigated ACs present in the anterior maxilla (3,4). Both studies employed a minimum detection diameter of 1.0mm (3,4). Oliveira-Santos *et al.* recorded the mean diameter of the AC's foramina to be 1.4mm with a range of 1.0 – 1.9 mm (3), and Von Arx *et al.* recorded the mean diameter of the ACs to be 1.31mm (±0.26 mm) with a range of 1.01 – 2.13 mm (4). Although both studies included direct extensions of CS, representing 42.1% and 61.2% of the sample group respectively, the diameters recorded in these studies may not necessarily represent the mean diameters of the ACs of CS (3,4) .

In summary, the studies of; Machado *et al.*, Shan *et al.*, and Tomrukçu & Köse determined the average diameter of the ACs of CS to be 1.19mm, 1.10mm and 1.07mm respectively (6,7,30). Machado *et al.* and Shan *et al.* employed a minimum diameter of 1.0mm (6,30), while Tomrukçu & Köse employed a minimum diameter of 0.5mm when measuring ACs (7). Beyzade *et al.* recorded the largest AC measuring 2.79mm in width (32). Studies by Machado *et al.*, Aoki *et al.*, and Beyzade *et al.* show that a low percentage (3.4 – 20%) of ACs exist at a diameter of greater than 1.0mm (6,27,32). Yeap *et al.* was the first to demonstrate the oval nature of CS finding considerable differences between the mean narrowest and mean widest diameters of CS (28). Table 3 summarises the findings of previous studies investigating the average diameter of AC of CS. Table 4 summarises the findings of two different studies investigating the average diameter of AC present in the anterior maxilla

Table 3: **Summary of the average diameter of AC of CS.**

Study	Minimum measurement diameter (mm)	Average diameter of AC of CS (mm)	Standard deviation (mm)	Range (mm)
Machado *et al.* (6)	1.0	1.19	0.22	1.00 - 2.58
Shan *et al.* (30)	1.0	1.10	0.10	1.00 - 2.10
Tomrukçu & Köse (7)	0.5	1.07	0.35	0.53 - 2.72

Table 4: **Summary of the average diameter of AC present in the anterior maxilla.**

Study	Minimum measurement diameter (mm)	Average diameter of ACs present in the anterior maxilla (mm)	Standard deviation (mm)	Range (mm)
Oliveira-Santos *et al.* (3)	1.0	1.40	-	1.00 - 1.90
Von Arx *et al.* (4)	1.0	1.31	0.26	1.01 - 2.13

2.5 Sex and canalis sinuosus and its accessory canals

Literature indicates that sex has very little impact on the presence of CS and its ACs (1–5,7,26,30).

The studies of; Wanzeler *et al.*, Oliviera Santos *et al.*, Orhan *et al.*, Tomrukçu & Köse, Ghandourah *et al.*, Shan *et al.*, Yeap *et al.,* and Beyzade *et al.* reported no significant difference between the presence of CS or its ACs and sex (1,3,5,7,26,28,30,32). While Gurler *et al.* and Von Arx *et al.* recorded a higher prevalence of ACs of CS among males than females, but without statistically significant differences (2,4). Furthermore, Gurler *et al.* recorded a significantly larger average diameter of CS among males than females, measuring 1.52mm and 1.30mm respectively (2).

However, four studies differ from the prevailing body of literature. Anatoly *et al.* recorded a statistically higher prevalence of CS among females than males within the Russian population (19). Conversely, Aoki *et al.* recorded a statistically higher frequency of CS in males than females in the Brazilian population (27). Machado *et al.* reported a significantly higher incidence of ACs of CS among males (*n* = 280/483; 58%) than females (*n* = 241/517; 46.6%) in the Brazilian population (6). Şalli & Öztürkmen reported a similar finding with a significantly higher incidence of ACs of CS among males (*n* = 36/351; 10.3%) than females (*n* = 19/322; 5.9%) in the Turkish population (31). The findings of these four studies may be due to inherent genetic differences within these population groups, but all demonstrate a male predilection. Table 5 summarises the findings of previous studies investigating the effect of sex on CS and its ACs.

Table 5: **Summary of the effect of sex on CS and its ACs.**

Study	Difference in prevalence between sexes	Statistically significant	Population
Wanzeler *et al.* (1)	None	No	Brazilian
Oliviera Santos *et al.* (3)	None	No	Belgian
Orhan *et al.* (5)	None	No	Turkish
Tomrukçu & Köse (7)	None	No	Turkish
Ghandourah *et al.* (26)	None	No	German
Shan *et al.* (30)	None	No	Chinese
Yeap *et al.* (28)	None	No	Australian
Beyzade *et al.* (32)	None	No	Cypriot
Gurler *et al.* (2)	Male predilection of ACs of CS	No	Turkish
Von Arx *et al.* (4)	Male predilection of ACs of CS	No	Swiss
Anatoly *et al.* (19)	Female predilection of CS	Yes	Russian
Aoki *et al.* (27)	Male predilection of CS	Yes	Brazilian
Machado *et al.* (6)	Male predilection of ACs of CS	Yes	Brazilian
Şalli & Öztürkmen (31)	Male predilection of ACs of CS	Yes	Turkish

2.6 Age versus prevalence of accessory canals

The literature indicates that age has little impact on the presence of CS and its ACs (1,6,7,19,27,30,31).

Wanzeler *et al.*, Machado *et al.*, Tomrukçu & Köse, Anatoly *et al.*, Aoki *et al.*, Shan *et al.*, and Şalli & Öztürkmen recorded no statistically significant differences between age and the existence of CS and the distribution of its ACs (1,6,7,19,27,30,31). Orhan *et al.* and Ghandourah *et al.* observed a greater prevalence of the ACs of CS in older age groups when compared to the age group below 18 years of age (5,26). However, this observation can be attributed to the reduced availability of CBCT scans of the age group below 18 years of age - leading to an exceedingly small sample size of this demographic.

2.7 Canalis sinuosus and impacted maxillary canines

Gurler *et al.* assessed 111 CBCT scans of patients with impacted maxillary canines in the Turkish population and observed the bilateral presence of CS in all cases, regardless of the distribution (bilateral or unilateral) or location of the impacted maxillary canines (2). Thus, Gurler *et al.* concluded that the presence of an impacted maxillary canine has no bearing over the existence of CS (2). This conclusion is supported by Orhan *et al.* who assessed 158 CBCT scans of patients with impacted maxillary canines and found no significant difference in the prevalence or distribution of CS (5). A possible explanation for this observation may lie in the difference in chronological development of these structures, with CS developing during foetal development and permanent maxillary canines developing during childhood.

Gurler *et al.* reported that the mean diameter of CS remained statistically consistent regardless of the presence or absence of an impacted canine (2). Furthermore, Gurler *et al.* reported that impacted canines were located on average 5.27mm away from CS with the shortest distance recorded at 0.75mm (2). Horizontally impacted canines were located significantly closer to CS than obliquely or vertically impacted canines (2). Due to the proximity of the two structures, there is a high risk of damage to the ASAN & ASAA during the surgical removal of an impacted canine, particularly those occupying a horizontal position (2). Thus, added caution should be exercised while performing such surgical interventions (2).

The study by Gurler *et al.* suggested that the presence of impacted canines seemed to have little effect on the terminal portion of CS with almost all samples terminating in its typical location in the nasal floor (2). A single case displayed the merger of the terminal portion of CS with the nasopalatine canal (2). The terminal portion of six cases (5.4%) gave rise to ACs in the form of direct bony extensions of CS (2). The ACs ran inferiorly towards the alveolar ridge and terminated in the anterior palate, most commonly (*n* = 5/8 cases) behind the lateral incisors (2). Eight accessory foramina were found across the six cases with an average diameter of 1.06mm and a range of 0.89 – 1.41mm (2). These observations are most likely due to the normal anatomical variation seen between individuals, rather than the effects of the impacted canines (2).

2.8 Canalis sinuosus and cleft lip and palate patients

Ferlin *et al.* investigated the anatomy and distribution of CS among cleft lip and palate (CLP) patients and compared those to findings to patients without CLP (33). Ferlin *et al.* examined 200 CBCT scans of patients with CLP and 100 CBCT scans of patients without CLP (33). The study was conducted in the Brazilian population and all patients presented over the age of 18 years (33). It is important to note that the CLP in all patients had already been repaired at the time of exam, most likely with alveolar bone graft surgery (33), and thus the possibility of previous damage and accompanying resorption of local anatomy may have affected the findings of this study.

Ferlin *et al.* observed CS bilaterally in all patients (100%) without CLP and in 96.5% of patients with CLP (33). Furthermore, CLP patients presented with a significantly higher prevalence of ACs of CS when compared to individuals without CLP, although this prevalence was not reported (33). The study recorded no significant difference in the prevalence of CS and its ACs between bilateral and unilateral CLP patients (33).

Ferlin *et al.* found patients presenting with unilateral CLP recorded a larger diameter of CS on the non-CLP side (33). The study also found that the ACs among CLP patients presented with a significantly larger mean diameter than patients without CLP

(33). However, measurements of the ACs were only taken of ACs measuring greater than 1mm (33). As previous literature indicates the majority of ACs exist below 1mm this finding may not be applicable to the general population (6,27,32).

Patients presenting with CLP recorded a greater mean diameter and higher prevalence of the ACs of CS and therefore present with a greater risk of neurovascular damage during invasive surgery (33). Many patients presenting with CLP may require extensive intervention, such as orthognathic surgery, for aesthetic and/or functional purposes (33). It is therefore critical that the clinician carefully examine a high quality CBCT scan prior to surgery in order to avoid neurovascular damage (33).

2.9 Assessment of knowledge of canalis sinuosus

Lopes-Santos *et al.* conducted an online questionnaire to assess the knowledge of CS amongst Brazilian oral health care practitioners (34). The questionnaire was completed by 405 dentists and dental students and consisted of three parts; 1) socio-demographical information of the participants, 2) questions regarding CBCT scans demonstrating CS, 3) assessment of prior knowledge of CS. The majority (70.5%) of respondents admitted to having no knowledge of CS prior to answering the questionnaire (34). Furthermore, the majority of respondents (65.3%) could not identify CS on a CBCT image illustrating a clear example of the structure (34). However, the study showed that prior knowledge of CS led to the positive identification of CS in CBCT scans. Thus, Lopes-Santos *et al.* advocated for continuous education, improved anatomical knowledge, and a greater proficiency in interpreting CBCT scans among dental professionals (34).

2.10 Potential complications from damage to CS

The most frequently reported clinical complication associated with CS is post-operative pain and paraesthesia (10–12). The possibility of severe intra-operative haemorrhage and the failure of osseointegration of dental implants following damage to CS have also been discussed in the literature, however these potential complications have not been verified (8,10–13). Finally, CS has proven to be a source of diagnostic uncertainty as it may resemble periapical pathology to the unknowledgeable practitioner and may potentially lead to endodontic mismanagement (35,36).

2.10.1 Pain & paraesthesia

Shintaku *et al.* reported three different cases of damage to CS, and its ACs, due to the placement of a dental implant in the anterior maxilla in the region of the central incisor, lateral incisor, and canine respectively (10). Post-operative CBCT evaluation of all three implants demonstrated that the apical aspect of the implant impinged upon CS (10). The affected patients reported sensations of; dysesthesia, sporadic pain, "*tightness of bone*", and pain during mastication (10). Clinical evaluation of the implants revealed no soft tissue pathology and further CBCT analysis revealed all other surfaces of the implants had achieved stable osseointegration (10).

Volberg and Mordanov detailed a case where injury to the ACs of CS occurred following the placement of a dental implant in the region of the maxillary lateral incisor (11). The aberrant implant caused severe pain and paraesthesia in the associated maxillary region and was removed 16 days post placement, relieving the symptoms (11). During clinical re-evaluation the clinician discovered that the administration of an infra-orbital local anaesthetic block relieved pain after palatal and incisive local anaesthetic blocks rendered no response (11). This, combined with comprehensive CBCT analysis, confirmed impingent of the ASAN within the AC of CS (11).

Arrude *et al.* reported a similar case of a 51 year old woman who presented with a 22 month history of pain and paraesthesia in the anterior maxilla and upper lip following the placement of a dental implant which damaged CS (12).

2.10.2 Implant osseointegration & haemorrhage

Ferlin *et al.*, Shintaku *et al.*, Volberg & Mordanov, Arrude *et al.* and McCrea postulate the potential for excessive intra-operative bleeding, and the failure of osseointegration of dental implants following damage to CS (8,10–13). However, at the time of writing, no clinical case reports were found in support of this claim. This may be due to clinicians' unwillingness to report their own iatrogenic damage or a lack of knowledge of the anatomical structure and its clinical relevance.

McCrea reported that in the case of one patient damage to the nasopalatine canal led to profound post-operative nasal bleeding, followed by a six month period of recurrent nasal bleeds, pain, swelling, and the sensation of nasal blockage (13). McCrea suggested that these consequences may similarly ensue following damage to CS (13).

2.10.3 Diagnostic considerations

Two case reports by Shah *et al.* and Shelley *et al.* indicate that when viewed exclusively on periapical radiographs, CS may imitate pathological entities such as; external root resorption, or periapical pathosis (35,36). Examples of these are illustrated in figure 7. This may lead the inexperienced/ill-informed practitioner to an incorrect diagnosis resulting in unnecessary and ineffective endodontic treatment (35,36). Furthermore, Shintaku and Volberg & Mordanov reported that periapical radiographs are inadequate for preoperative implant planning and that the use of CBCT scans are essential to avoid clinical complications during surgical intervention (10,11). Ferlin *et al.* concluded that CBCT scans are the best modality with which to evaluate CS (8). Improved knowledge of the prevalence, course and variations of CS will reduce the frequency with which diagnostic dilemmas and clinical complications occur.

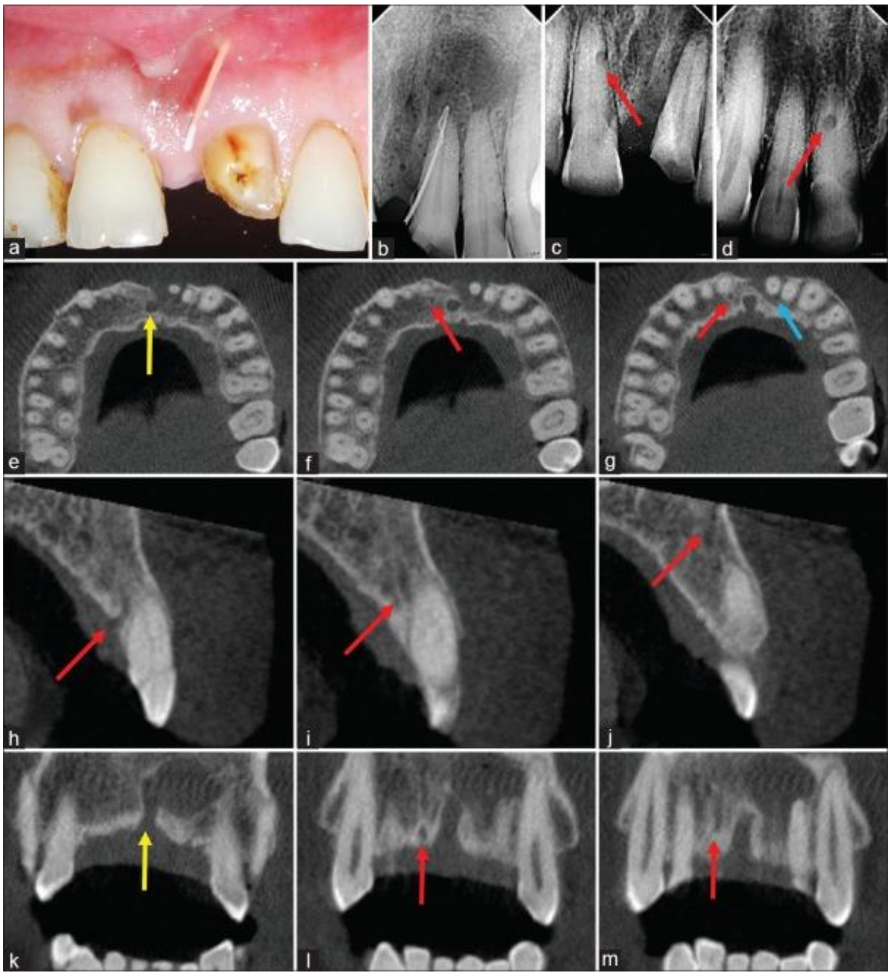

Figure 7: Clinical and radiographic images taken from a case reported by Shah et al. (35)*. The images illustrate the diagnostic confusion which may be caused by superimposition of an AC of CS over the root of a central incisor (11). The periapical radiographs demonstrate how an AC of CS may mimic external root resorption. The AC causing diagnostic confusion relative to the 11 is indicated by the red arrows, while another AC near the 21 is represented by the blue arrow, and the nasopalatine canal is indicated by the yellow arrows.*

3. Motivation

To date, no study exists regarding the prevalence, distribution or structure of CS or its ACs in the South African population. Therefore, the present study served to expand and update the current body of evidence by providing an accurate and reliable description of the relevant anatomy, as well as, a comprehensive account of the prevalence and distribution of CS across a sample of South African subjects.

4. Aims and objectives

The aim of this study was to determine the prevalence and distribution of CS, as well as, describe its anatomical variations within a sample of South African patients. This aim was addressed through the completion of the following objectives:

1. Determine the prevalence and diameter of CS among a subpopulation of patients attending the Pretoria Oral and Dental Hospital, University of Pretoria, South Africa.
2. Evaluate the relationship between the variables of sex, population group, age and the existence and sidedness of CS among the patients attending the Pretoria Oral and Dental Hospital, University of Pretoria, South Africa.
3. Determine the prevalence, number, mean diameter, and most common point of termination of the ACs of CS among the patients attending the Pretoria Oral and Dental Hospital, University of Pretoria, South Africa.
4. Describe the terminal positions of the ACs of CS.

5. Materials and methods

5.1 Study design

5.1.1 Overview

This cross-sectional retrospective study evaluated 500 CBCT scans of the anterior maxilla and recorded the prevalence, sidedness and diameter of CS, the distribution of CS across demographic data, as well as, the prevalence, number, mean diameter and point of termination of the ACs of CS. This information was used to classify and categorise the variations seen among the ACs of CS.

5.1.2 Setting

The study was conducted on the existing CBCT database available in the Section of Diagnostic Imaging, Department of Oral and Maxillofacial Pathology, Pretoria Oral and Dental Hospital, University of Pretoria, South Africa. Data collection occurred during the period from the 31st of July 2021 until the 31st of April 2022. The study was conducted under the supervision and assistance of two qualified dentists in the Departments of Odontology and Maxillo-Facial and Oral Surgery respectively.

5.1.3 Sample size

A total of 500 CBCT scans of the anterior maxilla were examined. This sample size was comparable to that of existing studies at the time of writing. Scans were evaluated retrospectively from the most recently acquired scan (as of the 31st of July 2021) until the necessary sample size was fulfilled. Convenience sampling was used for the purposes of this study. It was assumed that patients presented randomly to the Oral and Dental Hospital for treatment over the data collection period.

5.2 Analysis of canalis sinuosus and its accessory canals in South Africa

5.2.1 Acquisition of CBCT scans

This study retrospectively examined existing CBCT scans from the database available at the University of Pretoria. No new scans were acquired for the purpose of this study. All scans were originally taken for the benefit of the patient such as; the planning of dental implants, the diagnosis of maxillofacial trauma, and the assessment of endodontic and orthodontic cases. Throughout image acquisition the principle of "as low as diagnostically acceptable" (ALADA) was followed, thus ensuring patients were exposed to minimal ionising radiation during their radiological examination.

Experienced radiographers in the Section of Diagnostic Imaging, Department of Oral and Maxillofacial Pathology, in the School of Dentistry, Faculty of Health Sciences, at the University of Pretoria were responsible for the acquisition of all scans using a CBCT unit (Planmeca Pro-max 3D Max; Planmeca Oy, Helsingfors, Finland). The software of the same manufacturer (Planmeca Romexis, Planmeca Oy, Helsingfors, Finland) was used to view and analyse the scans.

The resolution of the CBCT unit varied between 100 – 600μm, with 300 to 750 basic frames. This corresponded to the range of voxel sizes (100 – 600μm) produced by the unit. The anode current and voltage was set between 8-14mA and 54-90kV respectively. The fields of view encompassed the entire maxilla, and the focal spot was set to 0.6×0.6mm in diameter. The exposure settings for each patient were individualised based on the requested field of view and clinical indication.

5.2.2 Sample selection

The following inclusion and exclusion criteria were followed for the selection of CBCT scans;

Inclusion criteria:

1. Only CBCT scans which contained the entire maxilla anterior to the second maxillary premolars bilaterally were included in the present study.

Exclusion criteria:

1. Partial/ unilateral imaging of anterior maxilla.
2. Low technical quality of CBCT scans – maximum voxel size of 400µm.
3. Pathological lesions which may have altered the course of CS and its ACs.
4. CBCT scans presenting with a missing tooth, implant or grafted alveolar ridge in the anterior maxilla.
5. CBCT scans presenting with a supernumerary or impacted tooth in the anterior maxilla.
6. A clearly visible history of trauma to the anterior maxilla (e.g.; visible fractures)
7. A clearly visible history of previous surgical intervention in the anterior maxilla (e.g.; orthognathic or trauma related surgery indicated by the presence of orthopaedic plates and screws).
8. The existence of radiographic artefacts which may have impeded the visualisation of the necessary structures.
9. Scans of population groups not classified as “Black African”, “White” or “Black African-foreign” (i.e.: those identified as Indian/Asian, Coloured, unspecified, etc.) on the yellow hospital file.

Scans satisfying the above-mentioned inclusion/ exclusion criteria were optimised for contrast, brightness, and sharpness. Furthermore, scans were viewed on a 22-inch medical grade monitor (BARCO MDRC-222, Kortrijk, Belgium) with a 2MP (1920 x 1080 pixels) resolution in a dimly lit room during scan analysis. This improved the level of accuracy and reliability of the results of this study.

All CBCT images were positioned into a standardised and reproducible orientation to facilitate consistency of analysis and measurement. The skull was aligned in the axial plane by positioning the anterior nasal spine, posterior nasal spine, and internal occipital crest (when visible) aligned to the mid-sagittal plane. Then the skull was thereafter aligned in the coronal plane by adjusting the medial-lateral head tilt by aligning the anterior nasal spine, nasal septum, and crista galli in a straight line parallel to the mid-sagittal plane. Finally, in the sagittal plane the superior-inferior head tilt was adjusted by aligning the anterior- and posterior nasal spine parallel to the axial plane of the CBCT scan.

5.2.3 Calibration of examination

All CBCT scans were examined by the primary investigator after calibration with the two supervisors – one with experience in endodontics and another with experience in oral surgery. The first 50 samples were examined by the investigator and both supervisors for the purposes of calibration and determination of inter-observer reliability. This represented 10% of the total sample. The primary investigator then examined the remaining 450 scans. Following examination of all 500 scans the primary investigator and two supervisors then re-examined the original 50 scans (used for calibration) to determine the intra-observer agreement using a Cohen's kappa test.

5.2.4 Documenting canalis sinuosus

5.2.4.1 Identification of canalis sinuosus

All CBCT images which satisfied the inclusion and exclusion criteria were examined in axial, coronal and sagittal planes for the presence of CS according to its typical anatomical description in the literature (1,2,9,15,17,18). The infraorbital canal served as the initial landmark from which all examinations began. This ensured consistency of detection and complete tracing of CS. Independent bilateral examination of the maxilla was performed to determine the prevalence, and potential difference in the sidedness of CS. After thorough examination the results were recorded in the data collection sheet (appendix A).

An identified canal was only considered to be CS if it satisfied the following criteria;

1. The canal typified the description of CS, i.e.; the canal;
    a. resided entirely within the maxilla,
    b. branched off the infraorbital canal, and
    c. coursed towards the inferior aspect of the lateral wall of the nasal aperture.

If an identified canal did not satisfy the above-mentioned criteria (e.g.: the canal did not branch off the infraorbital canal) it was marked as absent and no further consideration was given to the canal and its potential ACs.

Due to software limitations a minimum detection diameter of 0.5mm was set for the identification of CS. A minimum detection diameter of 0.5mm allowed for the finding of the present study to be compared to those of existing studies examining CS.

5.2.4.2 Measurement of canalis sinuosus diameter

Following identification of CS, the scan was positioned to visualise CS at its largest diameter, occurring along the portion of the canal which runs vertically adjacent to the nasal aperture. A measurement of the canal's diameter was recorded at this point in a coronal plane. The canal was measured with the use of a digital ruler available on the Romexis software. Measurements were recorded to two decimal places.

5.2.5 Documenting accessory canals of canalis sinuosus

5.2.5.1 Identification of accessory canals of canalis sinuosus

Following initial detection of CS, the examination and detection of potential ACs of CS commenced. The terminal portion of CS served as the initial location for detection of ACs in axial, coronal and sagittal planes. The presence and number of ACs were recorded for both the left- and right-, and the results were recorded on the data collection sheet.

An identified canal was only considered as an AC of CS if it satisfied the following criteria;

1. The canal was clearly visualised as either;
    a. A direct extension of CS beyond its typical point of termination; adjacent to the nasal septum anterior to the incisive canal, or
    b. A direct branch off CS in the case of multiple ACs.

If an identified canal did not satisfy the above-mentioned criteria (i.e.: the canal was not in direct communication with CS) it was regarded as absent and no further consideration was given to the canal.

Due to software limitations a minimum detection diameter of 0.5mm was set for identification of ACs. A minimum detection diameter of 0.5mm allowed for the present study to be compared to existing studies examining the ACs of CS.

5.2.5.2 Measurement of accessory canals diameter

Following the successful identification of an AC the scan was oriented to visualise the AC at its largest diameter in an axial plane. The AC's diameter was measured in two directions, perpendicular to one another, on the same axial slice. One measurement was taken at the widest point of the AC, and the second measurement at the narrowest point. The average of these two measurements was used as the final recorded measurement for the AC. This methodology is illustrated in figure 8. This is an important aspect of the methodology, as it compensates for the oval nature of CS and its AC, as determined by Yeap *et al.* (28).

A standardised point was not used for the measurement of the canal's diameter to accommodate for the variation in anatomy seen between individuals and facilitate ease of measurement. The canal was measured with the use of a digital ruler available on the Romexis software. Measurements were recorded to two decimal places.

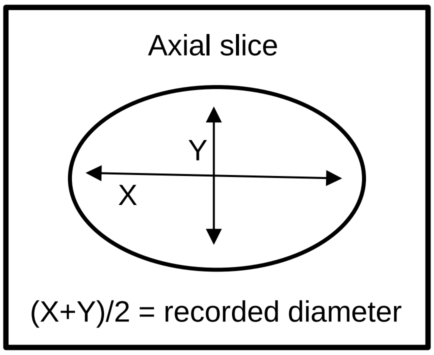

Figure 8: Illustration of the manner in which the diameter of the ACs were measured and recorded.

5.2.5.3 Determination of accessory canals point of termination

The ACs were traced from their point of origin until the canal exited the maxilla at a foramen. The regions of AC termination were recorded according to the proximity of the AC foramen to the maxillary teeth and incisive foramen. Predetermined locations included; buccal, transversal, and palatal locations relative to the central incisors, lateral incisors, canines and first premolars, as well as lateral and posterior to the incisive foramen. AC foramina which terminated in the region between two teeth were classified as such, thus differentiating between foramina which terminated in the region of a single tooth. These predetermined regions were similar to the work of Oliveira-Santos *et al.*, Orhan *et al.*, Machado *et al.*, Tomrukçu & Köse, Anatoly *et al.* and Şalli & Öztürkmen (3,5–7,19,31).

The point of termination of the ACs were recorded by the primary investigator. In cases of uncertainty the primary investigator requested guidance from the two supervisors. In the case of disagreement, the position of termination was discussed until consensus was reached. If consensus could not be reached a neutral, experienced dentist with experience in maxillofacial radiology determined the final recorded location of the AC termination.

Additional locations of AC termination were added to the predetermined locations of termination as the study progressed. Alternative points of termination included; points located in the mid-palatal region and points further posterior than the first premolar. All points of termination were qualitatively described, with the use of abbreviations, in the data collection sheet.

5.2.5.4 Description of accessory canal course

After all other data was collected a brief qualitative description of the AC's course was provided. The description followed the AC from its point of origin towards its point of termination. Descriptions included:

- CL – curved laterally
- CM – curved medially
- SV – straight vertical
- C-Distal – curved distally
- Other – an independent qualitative description

These patterns of configuration/ AC course lie in accordance with the work of Von Arx *et al.* and Tomrukçu & Köse (4,7). Other possible variations may include the AC branching to join the nasopalatine canal, however this variation was not observed in the present study.

5.3 Data collection

5.3.1 Data capturing

A spreadsheet (Microsoft Excel 2016, Microsoft corporation, Redmond, WA, USA) was used to collect and record the following variables for each CBCT scan; the presence, sidedness and diameter of CS, the presence, sidedness, number, point of termination, diameter, and course of the ACs of CS. The file number of each scan was recorded in order to retrospectively collect the necessary demographic data (sex, population group, age). The identity of the patient to which the CBCT scan belonged remained strictly anonymous to any external party viewing the results of this study. This was achieved by replacing the file number of the patient's CBCT scan with an anonymous sample number.

Appendix A demonstrates a sample of the data collection sheets.

5.3.2 Correlation of collected data with demographic data

Collected data was correlated with the demographic data available in the records of the Oral and Dental Hospital at the University of Pretoria. The collected data was entered into the data collection spreadsheet (Appendix A). The spreadsheet allowed for the capturing of the following data:

1. File number for internal use only (three letter abbreviation and four sequential numbers, i.e.; ABC1234), or sample number for external use (numeric value; 1 – 500),
2. Sex (male, female or unknown; unknown represented by a question mark)
3. Reported racial grouping (Black African, White, or Black African-foreign. The term "Black African-foreign" refers to individuals who self-identify as Black African but who were born outside of South Africa)
4. Age (numerical value, or unknown; unknown values represented by a question mark)
5. Presence of CS in the maxilla (yes or no)
6. Bilateral or unilateral presence of CS (bilateral or unilateral)
7. Diameter of CS on the left- and right- sides (recorded in millimetres)

8. Presence of ACs stemming from CS (yes or no)
9. Number of ACs (numerical value; left, right, total)
10. Point of termination of the ACs exiting the maxilla (described according to the FDI tooth numbering system and local anatomy. The following locations were used with buccal, transversal, and palatal differentiation; 15, 15-14, 14, 14-13, 13, 13-12, 12, 12-11, 11, 11-21, 21, 21-22, 22, 22-23, 23, 23-24, 24, 24-25, 25 lateral to the incisive foramen (right & left), posterior to the incisive foramen, mid-palatal locations were described using the point of intersection between two perpendicular lines each drawn from the central point of a maxillary tooth to the point of AC termination. The following abbreviations were used B = buccal, T = transversal, P = palatal, IF = incisive foramen, L = left, R = right. For reference an example of a possible abbreviated description is provided; P12 = the AC terminates palatal to the right lateral incisor)
11. The diameter of the AC (numeric value determined with digital measurements, recorded in millimetres)
12. The course of the AC (described qualitatively. The following abbreviations were used for description; CL – curved laterally, CM – curved medially, SV – straight vertical, C-Distal – curved distal, Other).

5.3.2.1 Definition of groups

During the South African National Census of 2011 the national statistical service of South Africa (Statistics South Africa) classified South Africans into five demographic groups; Black African, White, Coloured, Indian/Asian, and Other (37). This classification system stems from the Population Registration Act of 1950 implemented by the Apartheid government (38). At present this classification system is used by government health care facilities (including the Pretoria Oral and Dental Hospital) where patients are expected to self-identify to which demographic group they belong. In accordance with Statistics South Africa and the current practice of government health care facilities this paper employed the same method of demographic classification.

Nine defined groups were created to allow for comparison between the maxillae of different subjects. These groups were defined on the basis of sex, age, and population group. These groups included;

1. All patients
2. All male patients
3. All female patients
4. Black African patients
5. White patients
6. All patients ≤20 years of age
7. All patients between 21-40 years of age
8. All patients between 41-60 years of age
9. All patients ≥61 years of age

5.4 Description of the terminal positions of the accessory canals of canalis sinuosus

Following thorough examination of all CBCT scans and the collection of data the regional termination of the ACs of CS were categorised by means of a diagram which illustrated the frequency and position of the points of termination of the ACs. The diagram combined and resembled the diagrams developed by Oliveira-Santos *et al.* and Machado *et al.* represented by figures 6 & 9 (3,6).

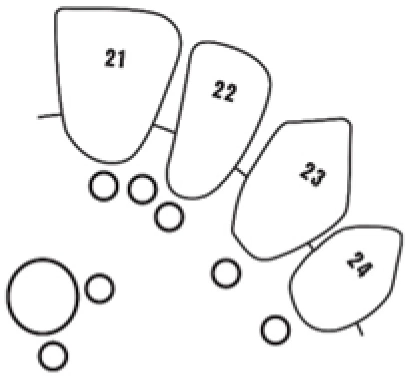

Figure 9: A Diagram based on the work of Oliveira-Santos et al. depicting the various points of termination of the ACs of CS (3). Developed by Creative Studios University of Pretoria.

5.5 Data analysis

Data was captured in a Microsoft Excel 2016 spreadsheet and imported into Statistical Analysis Software (SAS Institute Inc, Cary, NC, USA) for statistical analysis. Demographic and clinical characteristics were summarised descriptively. Continuous variables (e.g.; age, diameter of AC) were summarised by mean, standard deviation, median, interquartile range, minimum and maximum values. Categorical variables (e.g.; gender, presence of AC) were summarised by frequency counts and percentage calculations.

The prevalence of a characteristic was calculated as the percentage of subjects in the sample demonstrating the particular characteristic, together with a 95% confidence interval.

Percentages were compared using chi-squared or Fisher Exact tests depending on the sample size. Mean values were compared by analyses of variance (ANOVA). Median values were compared using the Kruskal-Wallis test.

Results were presented in tables and a graph.

All statistical tests were two-sided and p values ≤ 0.05 were considered significant.

5.6 Reliability and validity

The assessment tools used in the present study were the Data Collection Sheets in Appendix A, which were compiled by the investigator in clearly phrased factual questions, for the specific purpose of assessing characteristics associated with CS and its ACs.

Data was transcribed by the investigator from the patient files onto the Data Collection Sheets. Transcriptions were objective and honest without any corrections or manipulations of results, or substitutions for missing or doubtful data. The same forms were used for all participants. The reliability and validity of the data as recorded in the patient files by the treating dentists was assumed.

5.7 Bias

Bias was avoided/controlled for in the present study as follows:

- Selection bias was avoided by including all subjects that complied with the inclusion criteria during the data collection period.
- The use of the same Data Collection Sheet for all subjects.
- Conclusions were based on the results of statistical analysis of the data by an independent statistician.

5.8 Ethical considerations

The CEO of the School of Dentistry, the Head of Department of Odontology, and Head of Department Oral and Maxillofacial Pathology granted permission to conduct the study. Ethical approval was obtained from the Research Committee of the School of Dentistry (RESCOM) (approval number; 2021/17) (Appendix B) as well as the Research Ethics Committee of the Faculty of Health Sciences, University of Pretoria (Ethics reference number: 428/2021) (Appendix C).

The data gathered from all subjects remained anonymous to all external parties and the privacy of all participants was protected. The research subjects' right to privacy, as it is stipulated by the HPCSA in the document: 'General ethical guidelines for health researchers' were upheld. All research samples were treated with respect and dignity. All procedures followed the ethical standards of the Helsinki Declaration of 1975, as revised in 2008 (Appendix D).

6. Results

A total of 500 CBCT scans were included according to the selection criteria and examined for the prevalence, sidedness and diameter of CS. The prevalence, number, mean diameter, and most common point of termination of the ACs of CS was also evaluated. Following analysis of the initial 500 CBCT scans, 22 were excluded due to unavailable demographic information such as sex, population group, or age. A further 22 CBCT scans were additionally selected and examined to satisfy the desired sample size.

Data was captured on Microsoft Excel spreadsheets (Microsoft Corporation, Redmond, WA, USA) and statistical procedures were performed using SAS (SAS Institute Inc, Cary, NC, USA), Release 9.4. The statistical analysis included both descriptive and inferential statistics. All statistics were calculated by a biostatistician (Appendix E).

6.1 Reliability of scan assessments

A sample of 50 scans were assessed for the presence of CS by the primary investigator as well as each of the two study supervisors. Inter-rater agreement was found to be high between all observers. Perfect agreement was found between the two supervisors (n = 50/50, 100%, Kappa score = 1), and near-perfect agreement between the supervisors and the primary investigator (n = 49/50, 98%, 95% confidence interval (CI): 89.5 – 99.6%), respectively.

Intra-rater agreement was also found to be high (n = 49/50, 98%). Upon re-assessment of the 50 selected scans by the primary investigator, only one disagreement was observed. The Kappa statistic was not mathematically calculable in this case. Based on these findings, the scan assessments were regarded as reliable for further analysis.

6.2 Demographic characteristics of the study sample

The final sample included 500 acceptable subjects. The majority of the subjects were male (*n* = 308/500, 61.6%), and the remainder were female (*n* = 192/500, 38.4%). Black African subjects represented 74.6% (*n* = 373/500) of the sample, while White subjects represented 17.0% (*n* = 85/500), and a further 8.4% (*n* = 42/500) of subjects were classified as Black African-foreign.

Subject age ranged between 10 and 89 years, with a mean age of 36.4 years (±13.9 years), a median age of 34 years and an inter-quartile range (IQR) of 27-44 years. Table 6 presents the distribution of age across the study sample of the present study, while figure 10 represents the distribution of sex and age across the study sample.

Table 6: Distribution of age across the study sample

Age, years	Frequency	Percentage
10 - 20	49	9.8
21 - 40	285	57.0
41 - 60	136	27.2
≥ 61	30	6.0
Total	**500**	**100**

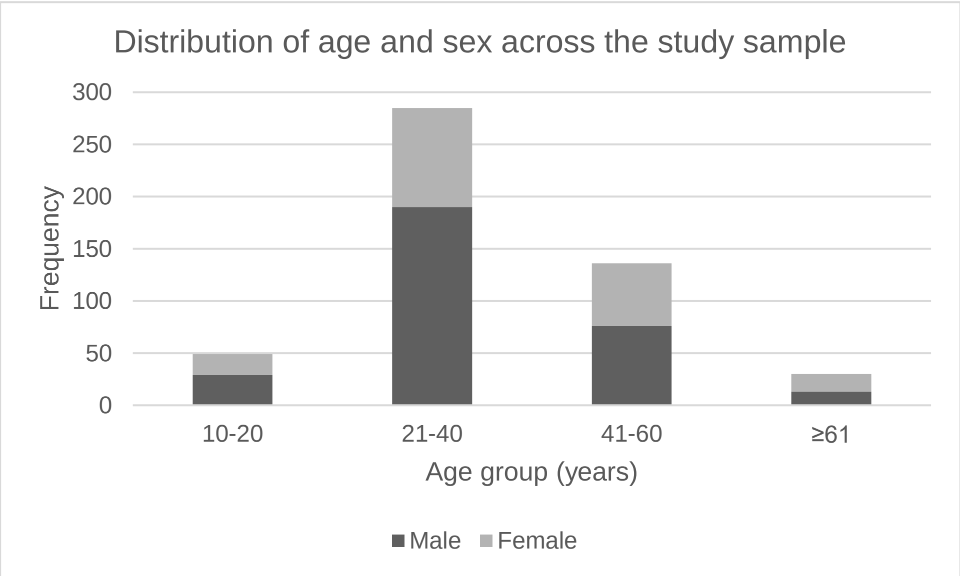

Figure 10: Bar graph representing the distribution of sex and age across the study sample of the present study.

6.3 Prevalence, sidedness, and diameter of canalis sinuosus

CS was present in the vast majority of subjects (*n* = 498/500, 99.6%), whilst only absent in a minority of cases (*n* = 2/500, 0.4%). In subjects where CS was present, the structure was most frequently observed bilaterally (*n* = 492/498, 98.8%), while infrequently occurring unilaterally (*n* = 6/498, 1.2%).

The diameter of CS ranged between 0.50mm – 2.39mm of the left, and 0.50mm – 2.37mm on the right. Table 7 illustrates the mean and median diameters of CS.

For the purposes of statistical analysis, CS canals were considered dependent variables (as a single patient may have presented with a paired set of CS canals, one on the left and one on the right). Therefore, statistical analysis of the CS diameters on the left side and on the right side included:

(i) Pearson and Spearman correlations between diameter measurements on the left and the right sides.

(ii) Calculation of the mean and median values for the left and for the right sides, and testing for significant differences between the mean and the median values, using statistical tests for paired observations.

These tests are represented in table 7.

Table 7: **Statistical analysis of the CS diameters**

Assessment	Value	*P* value
Mean (±SD), mm		
n	500	
Left	1.08 (±0.34)	0.646#
Right	1.08 (±0.31)	
Median (IQR), mm		
n	500	
Left	1.05 (0.85 – 1.29)	0.478**
Right	1.08 (0.87 – 1.26)	
n	500	
Pearson correlation	r = 0.742	<0.001*
Spearman correlation	r_s = 0.733	<0.001*

*z test

Paired t test

** Signed ranks test

Both correlation coefficients were highly significant (*P* < 0.001).

No statistically significant difference between the mean values (*P* = 0.646).

No statistically significant difference between the median values (*P* = 0.478).

No significant difference between the mean or median values of the left or right diameters of CS were observed. Furthermore, within a single patient, diameters of CS were highly likely to be correlated.

6.4 Effect of demographics on the prevalence and sidedness of canalis sinuosus

6.4.1 Effect of sex on canalis sinuosus

6.4.1.1 Prevalence

All females in the study sample presented with CS (*n* = 192/192, 100%), while the majority of males (*n* = 306/308, 99.4%) also presented with CS. Only two male subjects presented without CS (*n* = 2/308, 0.6%). A 95% CI revealed a prevalence of 97.7% – 99.8% for males and 98.0% – 100% for females. Fisher exact tests concluded that the prevalence of CS between males and females (99.4% vs 100%) did not differ significantly (*P* = 0.526). Therefore, the presence of CS was not related to sex.

6.4.1.2 Sidedness

Where present, the majority of both males (*n* = 304/306, 99.4%) and females (*n* = 188/192, 97.9%) presented with CS bilaterally. A minority of cases presented unilaterally for males (*n* = 2/306, 0.6%) and females (*n* = 4/192, 2.1%). Male subjects demonstrated two cases (0.6%) unilaterally on the right, while female subjects demonstrated three cases (1.6%) unilaterally on the left and one case (0.5%) unilaterally on the right. Fisher exact tests showed the prevalence of males and females presenting with a bilateral (99.4% vs 97.9%) or unilateral (0.6% vs 2.1%) distribution of CS did not differ significantly (*P* = 0.211). The sidedness of CS was therefore not sex related.

6.4.2 Effect of population group on canalis sinuosus

The results in this section were presented for patients classified as Black African or White (i.e., South African subjects only) and therefore excluded 42 subjects classified as Black African-foreign (non-South African subjects).

6.4.2.1 Prevalence

All White subjects presented with CS (*n* = 85/85, 100%). The majority of Black African subjects presented with CS (*n* = 371/373, 99.5%), while the remaining minority of

Black African subjects did not (*n* = 2/373, 0.5%). Fisher exact tests concluded that the prevalence of CS among Black African and White patients (99.5% vs 100%) did not differ significantly (*P* = 1.000). Therefore, the presence of CS was not related to population group.

6.4.2.2 Sidedness

Where present, the majority of Black African subjects (*n* = 368/371, 99.2%) and White subjects (*n* = 83/85, 97.6%) presented with CS bilaterally. A minority of cases presented unilaterally in Black African subjects (*n* = 3/371, 0.8%) and White subjects (*n* = 2/85, 2.4%). Black African subjects demonstrated two cases (0.5%) unilaterally on the right and one case (0.3%) on the left. White subjects displayed two cases (2.4%) unilaterally on the right. Fisher exact tests demonstrated no significant differences (*P* = 0.235) regarding the prevalence of Black African and White subjects presenting with a bilateral (99.2% vs 97.6%) or unilateral (0.8% vs 2.4%) distribution of CS. Sidedness of CS was therefore not related to population group.

6.4.3 Effect of age on canalis sinuosus

6.4.3.1 Prevalence

The effect of age on the prevalence of CS is described in Table 8:

Table 8: Prevalence of CS by age

Assessment	**Age, years**				***P* value***
	≤20 (%)	**21-40 (%)**	**41-60 (%)**	**≥61 (%)**	
CS absent	-	2 (0.7)	-	-	1.000
CS present	49 (100)	283 (99.3)	136 (100)	30 (100)	
Total	49 (100)	285 (100)	136 (100)	30 (100)	
Prevalence	**100%**	**99.3%**	**100%**	**100%**	
95% CI	**92.7 - 100%**	**97.5 - 99.8%**	**97.2 – 100%**	**88.6 – 100%**	

*Fisher Exact test

Table 8 shows that the prevalence of CS across the four age categories; ≤20, 21-40, 41-60, and ≥61 years (100%, 99.3%, 100%, 100%) did not differ significantly (*P* = 1.000). The presence of CS was therefore not age related.

6.4.3.2 Sidedness

The effect of age on the sidedness of CS is described in Table 9:

Table 9: Sidedness of CS by age

Sidedness	Age, years				*P* value*
	≤20 (%)	**21-40 (%)**	**41-60 (%)**	**≥61 (%)**	
Unilateral **	1 (2.0)	3 (1.1)	-	2 (6.7)	0.029
Bilateral	48 (98.0)	280 (98.9)	136 (100)	28 (93.3)	
Total	**49 (100)**	**283 (100)**	**136 (100)**	**30 (100)**	

*Fisher Exact test

** Patients ≤20 years of age: Left 0 (0.0%), Right 1 (2.0%).

Patients 21-40 years of age: Left 1 (0.4%), Right 2 (0.7%).

Patients 41-60 years of age: Left 0 (0.0%), Right 0 (0.0%).

Patients ≥61 years of age: Left 0 (0.0%), Right 2 (6.7%).

A relationship between sidedness and age was demonstrated in Table 9 (P = 0.029). Pairwise comparisons of the values in the four age categories showed a significant difference between the values in the age categories 41-60 years and ≥61 years (*P* = 0.032, Fisher Exact test). Compared against a Bonferroni adjusted *P* level of 0.008 the difference was not considered statistically significant, but only of clinical interest. Therefore, there was no significant difference in the sidedness of CS across different age categories.

6.3 Analysis of accessory canals

6.3.1 Prevalence and sidedness of the accessory canals

A total of 535 ACs were observed, 49.9% (*n* = 267/535) of ACs were found on the left and 50.1% (*n* = 268/535) on the right. The highest number of ACs observed in a single patient was seven. ACs were found in 58.8% (*n* = 294/500, 95% CI: 54.4 – 63.0%) of cases, and not seen in the remaining 41.2% (*n* = 206/500). In cases where ACs were found 42.9% (*n* = 126/294) occurred bilaterally and 57.1% (*n* = 168/294) occurred unilaterally. Little difference was found in the number of ACs occurring unilaterally on the left (*n* = 85/294, 28.9%) or right (*n* = 83/294, 28.2%).

6.3.2 Diameters of the accessory canals

When present, the diameter of the ACs ranged between 0.50mm – 1.28mm on the left, and 0.50mm – 1.52mm on the right. Mean and median values were calculated for the diameters of all the ACs by sidedness. Table 10 illustrates the mean and median diameters of the ACs.

ACs were not considered as paired as these structures frequently (*n* = 168/294, 57.1%) presented with a unilateral distribution, and frequently occupied different left and right distributions. Furthermore, a single subject may have presented with multiple ACs on the left, right, or both sides. Therefore, statistical assessments on the two sides were considered independent. Accordingly, mean and median values for the two sides were compared by statistical tests for independent samples and are presented in table 10.

Table 10: **AC diameters**

Assessment	Value	*P* value
Mean diameter (±SD), in mm		
Left	0.86 (±0.28)	0.834*
Right	0.87 (±0.27)	
Median diameter (IQR), in mm		
Left	0.80 (0.68 – 0.92)	0.678**
Right	0.82 (0.67 – 0.96)	

* Two-sample t test

** Wilcoxon rank sum test

No statistically significant difference found between the mean values (*P* = 0.834).
No statistically significant difference found between the median values (*P* = 0.678).

No significant differences between the mean or median values of the left or right diameters of the ACs of CS were observed.

6.3.3 Course of the accessory canals

All ACs (*n* = 535/535, 100%) progressed through the maxilla from a superior point of origin to an inferior point of termination. The course of the ACs could be classified into five distinct patterns;

1. Straight vertical – ACs which progressed anteriorly with no medial or lateral deviation in course.
2. Curved medially – ACs with a significant medial deviation in course.
3. Curved laterally – ACs with a significant lateral deviation in course.
4. Curved distally – ACs which turned to progress distally.
5. Other – an anatomical anomaly.

The most common AC configuration was the straight vertical configuration which represented 72.3% (*n* = 387) of ACs, followed by the curved distally configuration 12.7% (*n* = 68). ACs which curved laterally and ACs which curved medially represented 7.5% (*n* = 40) and 7.3% (*n* = 39) respectively. Only one case presented as an anatomical anomaly (*n* = 1/535, 0.2%). Table 11 describes the number and percentage of the ACs occurring in each pattern of configuration and compares the differences between left and right sides.

Table 11: Course of the AC

Classification	Left (%)	Right (%)	*P* value*
Straight vertical (387; 72.3%)	194 (72.6)	193 (72.0)	0.923
Curved medially (39; 7.3%)	20 (7.5)	19 (7.1)	0.870
Curved laterally (40; 7.5%)	19 (7.1)	21 (7.8)	0.869
Curved distally (68; 12.7%)	33 (12.4)	35 (13.1)	0.897
Other (1; 0.2%)	1 (0.4)	-	0.499
Total (535; 100%)	**267 (100)**	**268 (100)**	

* Fisher Exact test

No significant differences were found in the course of the ACs between the left and right sides.

Figures 11 -15 provide examples of each type of AC configuration.

Straight Vertical:

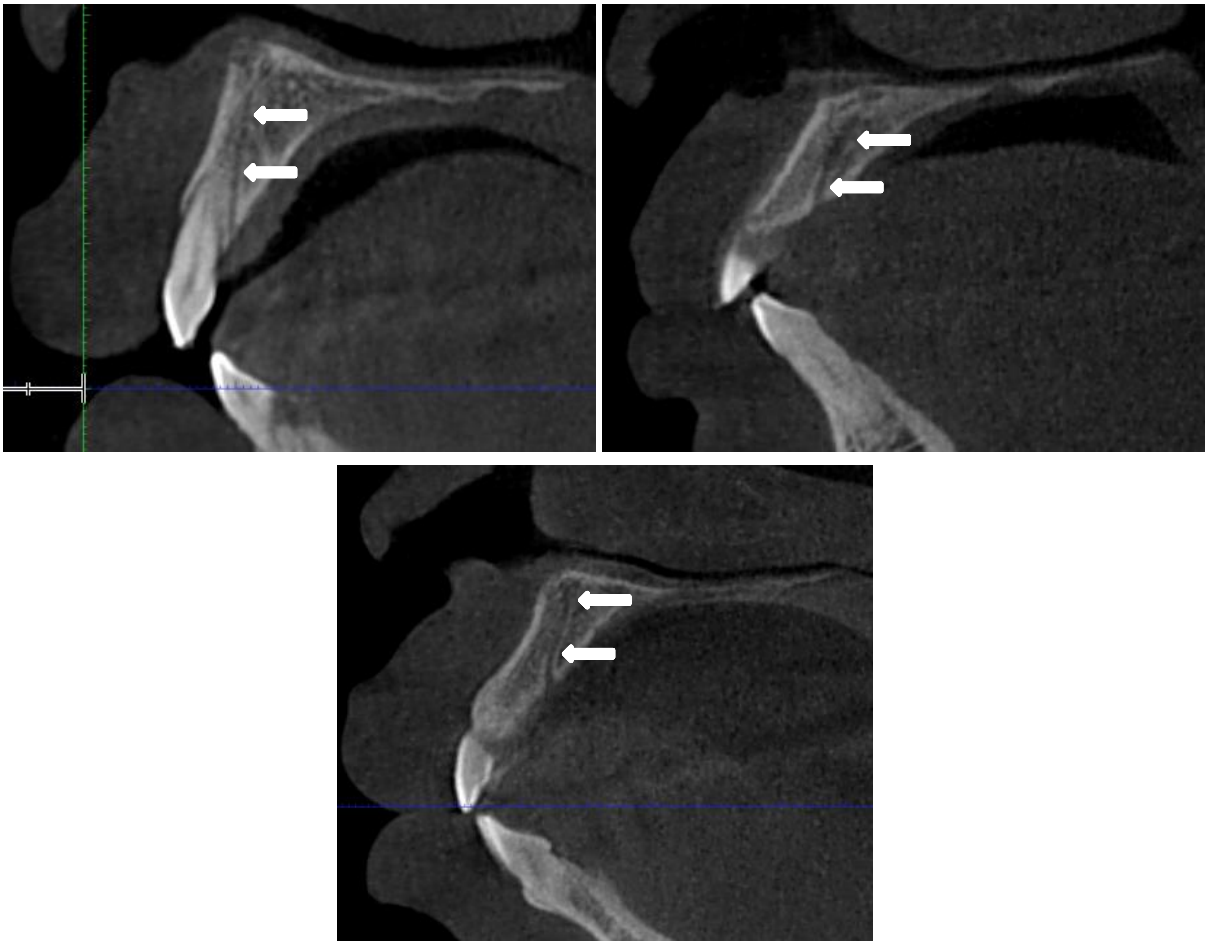

Figure 11: Demonstrates three examples of ACs of CS occupying a straight vertical position indicated by the white arrows. These structures were best viewed in the sagittal plane.

<u>Curved Medially</u>

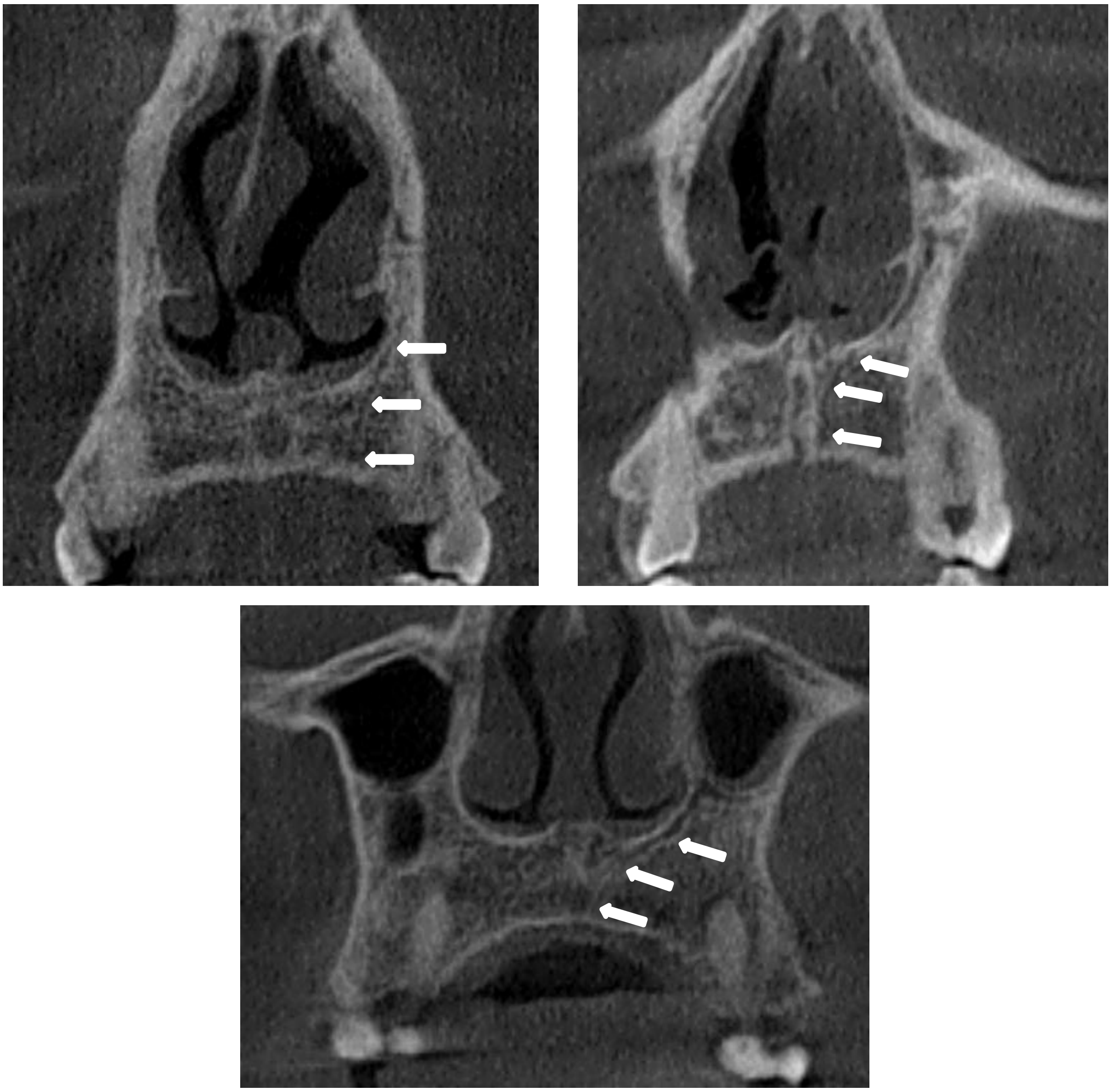

Figure 12: Demonstrates three examples of ACs of CS occupying a curved medial configuration indicated by the white arrows. These structures were best viewed in the coronal plane.

Curved Laterally:

Figure 13: Demonstrates three examples of ACs of CS occupying a curved lateral configuration indicated by the white arrows. These structures were best viewed in the coronal plane.

Curved Distally:

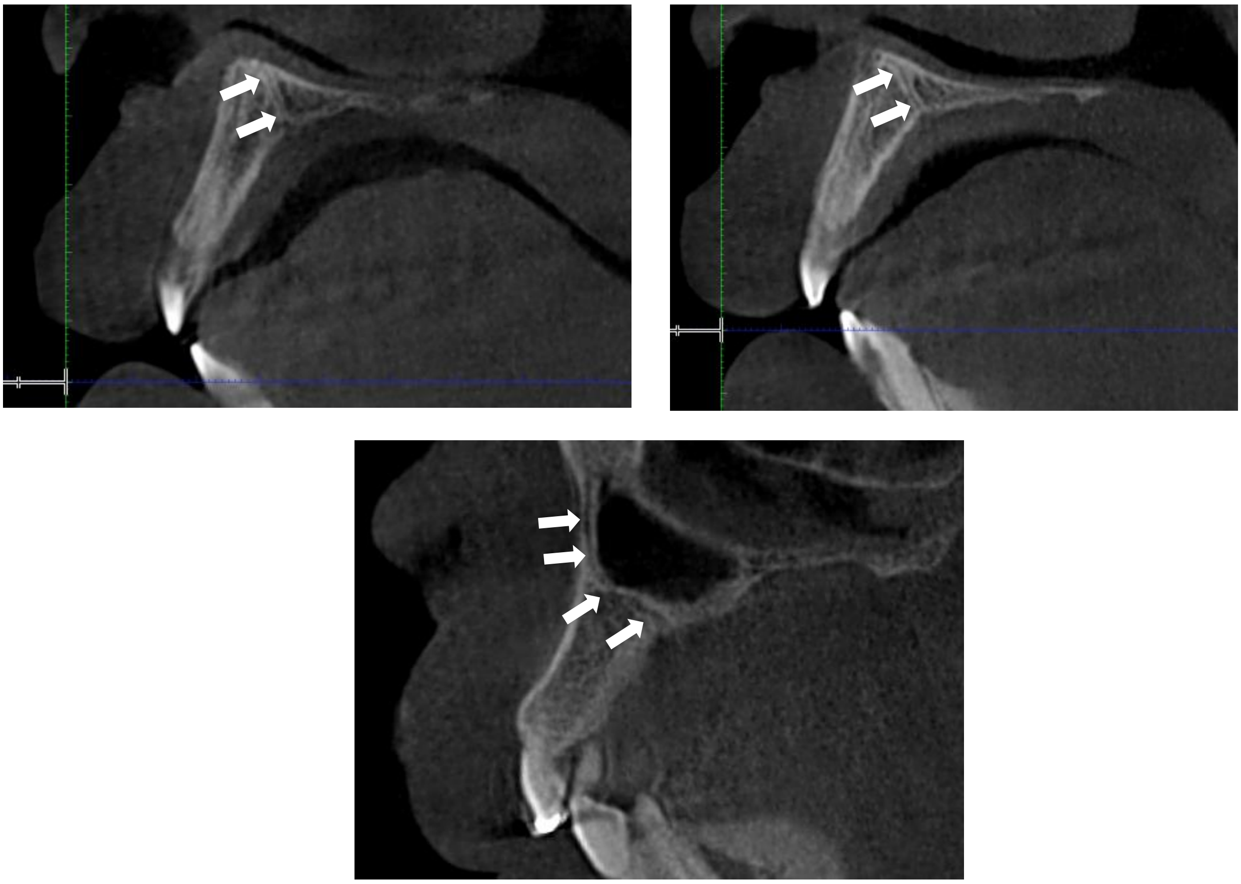

Figure 14: Demonstrates three examples of ACs of CS occupying a curved distal configuration indicated by the white arrows. These structures were best viewed in a sagittal plane.

Other:

This pattern represents a single (0.2%) anatomical anomaly which was described as assuming the appearance of a Christmas tree.

Figure 15: Example of an AC classified as an anatomical anomaly. The AC on the LHS of the maxilla branches off the horizontal aspect of CS and descends vertically before splitting into multiple branches inferiorly indicated by the white arrows.

6.3.4 Terminal positions of the ACs of CS

The terminal positions of ACs were described in graphical form, in line with the methodologies of previous studies (3,6). Examples are demonstrated in figures 6 & 9. The terminal positions of the ACs were described in relation to their position relative to teeth (described according to the FDI tooth numbering system), as well as local anatomical structures of the maxilla. Five principal regions of termination of the ACs were observed, namely;

1. Palatal of the maxillary teeth,
2. Transversal of the maxillary teeth,
3. Buccal of the maxillary teeth,
4. Mid-palatal, and
5. Near the incisive foramen

6.3.4.1 All accessory canals

The majority of ACs terminated in the anterior palatal region accounting for 57.2% (*n* = 306/535) of all detected ACs. A substantial portion (*n* = 116/535, 21.7%) of the ACs occupied a buccal position, with 10.5% (*n* = 56/535) found in a transversal position. A minority of ACs terminated in the mid-palatal region (*n* = 37/535, 6.9%) with even fewer ACs terminating near the incisive foramen (*n* = 20/535, 3.7%).

6.3.4.2 Accessory canals on the left

A total of 267 AC terminated on the left. The most common region of termination was the palatal region with 58.3% (*n* = 156/267) of ACs terminating palatal to the maxillary teeth. This was followed by 21.3% (*n* = 57/267) which terminated in a buccal position, and a further 8.5% (*n* = 23/267) in a transversal position. A minority of cases terminated in a mid-palatal region (7.8%, *n* = 21/267), and even fewer near the incisive foramen (3.7%, *n* = 10/267). One case (0.4%, *n* = 1/267) represented an anatomical anomaly which could not be classified according to the methodology of Oliveira-Santos *et al.* and Machado *et al.* (3,6), and was described as the “Christmas Tree” variation. A detailed account of the individual positions of termination of ACs found on the left is demonstrated in table 12.

Table 12: **Individual points of termination of ACs on the left**

Point of Termination Described relative to the FDI tooth numbering system and local anatomy	**Total number of left ACs** ***n* = 267**	**Percentage (%)**
Palatal (Total = 156)		
21-11 / 11-21	12	4.5
21	50	18.7
21-22	18	6.7
22	30	11.2
22-23	7	2.6
23	22	8.2
23-24	8	2.9
24	5	1.9
24-25	4	1.5
Buccal (Total = 57)		
21-11 / 11-21	39	14.6
21	8	2.9
21-22	3	1.1
22	3	1.1
22-23	0	0.0
23	0	0.0
23-24	3	1.1
24	0	0.0
24-25	1	0.4
Transversal (Total = 23)		0.0
21-11 / 11-21	16	6.0
21-22	1	0.4
22-23	1	0.4
23-24	2	0.7
24-25	3	1.1
Mid-Palatal (Total = 21)		
P21. Perpendicular 21-23	1	0.4
P21-22. Perpendicular 23	1	0.4
P22. Perpendicular 22-24	1	0.4
P22-23. Perpendicular 21-24	2	0.7

P23. Perpendicular 22-24	3	1.1
P24. Perpendicular 22-24	2	0.7
P24. Perpendicular 22-25	3	1.1
P24. Perpendicular 23-24	2	0.7
P24. Perpendicular 23-25	2	0.7
P24. Perpendicular 23-26	1	0.4
P24-25. Perpendicular 23-25.	1	0.4
P25. Perpendicular 23-25	1	0.4
P25-26. Perpendicular 23-26.	1	0.4
Incisive Foramen (Total = 10)		
Left	9	3.4
Posterior	1	0.4
Other (Total = 1)		
Anatomical anomaly described as the “Christmas Tree Variation”	1	0.4

Table 12 illustrates that the most common single point of termination on the left occurred palatal of the 21 (*n* = 50), followed by the buccal interproximal region of the 21-11 (*n* = 39). This was followed by palatal of the 22 (*n* = 30), and palatal of the 23 (*n* = 22). Other regions of interest included; palatal of the 21-22 (*n* = 18), the transversal interproximal region of the 21-11 (*n* = 16), and left of the incisive foramen (*n* = 9).

<u>6.3.4.3 Accessory canals on the right</u>

A total of 268 AC terminated on the right. The most common region of termination was the palatal region with 56.0% (*n* = 150/268) of ACs terminating palatal to the maxillary teeth. This was followed by 22.0% (*n* = 59/268) which terminated in a buccal position, and a further 12.3% (*n* = 33/268) in a transversal position. A minority of cases terminated in a mid-palatal region (*n* = 16/268; 6.0%), while even fewer terminated near the incisive foramen (*n* = 10/268; 3.7%). A detailed account of the individual positions of termination of ACs found on the right is demonstrated in table 13.

Table 13: Individual points of termination of ACs on the right

Point of Termination Described relative to the FDI tooth numbering system and local anatomy	**Total number of right ACs** ***n* = 268**	**Percentage (%)**
Palatal (Total = 150)		
11-21 / 21-11	8	3.0
11	53	19.8
11-12	11	4.1
12	26	9.7
12-13	7	2.6
13	18	6.7
13-14	11	4.1
14	10	3.7
14-15	4	1.5
15	2	0.7
Buccal (Total = 59)		
11-21 / 21-11	34	12.7
11	14	5.2
11-12	5	1.9
12	3	1.1
12-13	1	0.4
13	0	0.0
13-14	2	0.7
14	0	0.0
14-15	0	0.0
15	0	0.0
Transversal (Total = 33)		
11-21 / 21-11	17	6.3
11-12	5	1.9
12-13	3	1.1
13-14	6	2.2
14-15	2	0.7
Mid-Palatal (Total = 16)		
P11. Perpendicular 11-13	1	0.4
P11. Perpendicular 11-15	1	0.4

P13. Perpendicular 12-14	1	0.4
P14. Perpendicular 11-14	1	0.4
P14. Perpendicular 12-14	4	1.5
P14. Perpendicular 12-15	3	1.1
P14. Perpendicular 13-15	3	1.1
P14-15. Perpendicular 12-15	1	0.4
P15. Perpendicular 13-16	1	0.4
Incisive Foramen (Total = 10)		
Right	8	3.0
Posterior	1	0.4
Into	1	0.4

Table 13 illustrates that the most common single point of termination on the right occurred palatal of the 11 (*n* = 53), followed by the buccal interproximal region of the 11-21 (*n* = 34), then palatal of the 12 (*n* = 26), and palatal of the 13 (*n* = 18). Other regions of interest included; the transversal interproximal region of the 11-21 (*n* = 17), buccal of the 11 (*n* = 14), and palatal of the interproximal area between the 13-14 (*n* = 11).

6.3.4.4 Individual points of termination of ACs bilaterally

When bilateral positions were considered, the most common points of AC termination in the present study occurred; palatal of the central incisors (*n* = 103/535, 19.3%), buccal of the interproximal region between the central incisors (*n* = 73/535, 13.6%), palatal of the lateral incisors (*n* = 56/535, 10.5%), and palatal of the canines (*n* = 40/535, 7.5%).

6.3.4.3 Diagrammatic representation

A combination of the diagrams developed by Oliveira-Santos *et al.* (3) (figure 9) and Machado *et al.* (6) (figure 6) were used to create figure 16 and 17 below which visually represented the various points of termination of the ACs described in tables 12 and 13. Figure 16 depicts the points of AC termination according to the five principal regions of termination, while figure 17 depicts the ACs terminating in the mid-palatal region in greater detail.

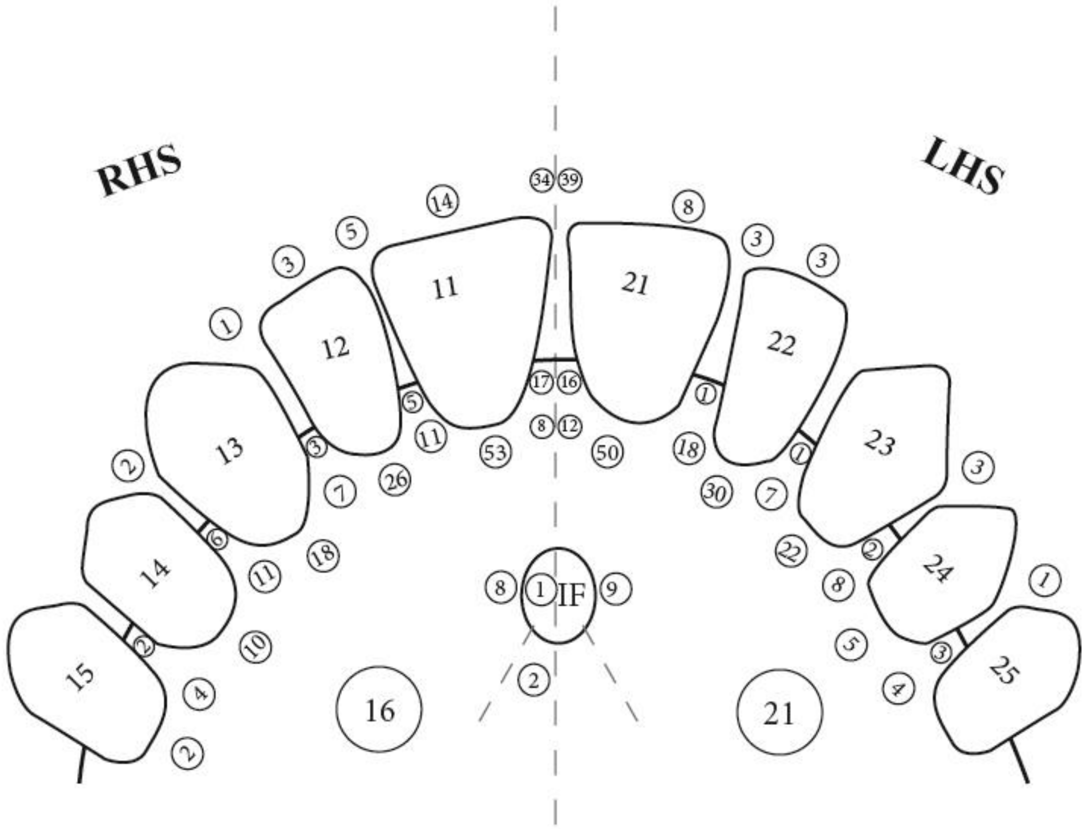

Figure 16: Illustration of the points of termination of the ACs found in the present study divided into five principal regions, namely; buccal, transversal, palatal, near the incisive foramen, and mid-palatal.

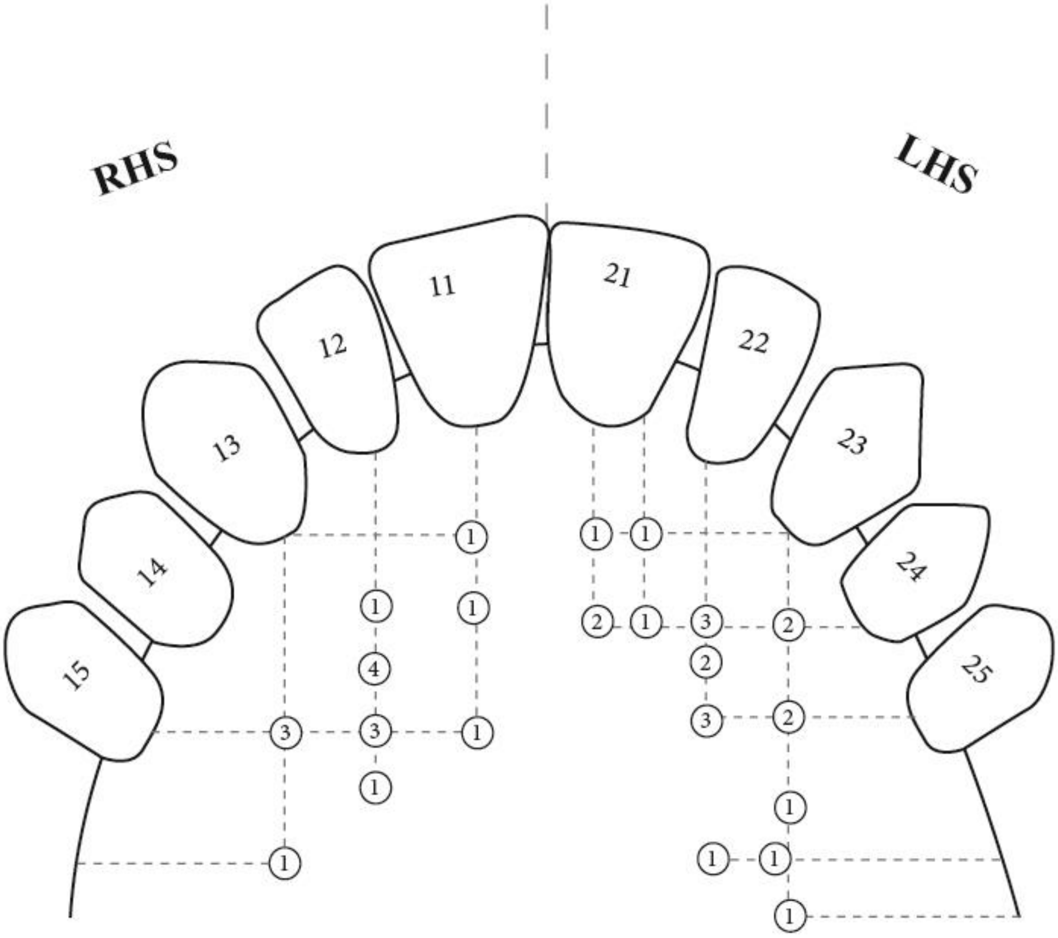

Figure 17: Illustration of the points of termination of the ACs terminating in the mid-palatal region of the present study.

7. Discussion

CS is a clinically important structure which may affect surgical procedures in implantology, oral surgery, endodontic surgery, and periodontal procedures (8,10–13,35,36). Damage to CS has been reported to cause post-operative pain and paraesthesia (10–12), intra-operative haemorrhage, and failure of osseointegration of dental implants (8,10–13). Furthermore, CS has been shown to be a source of diagnostic uncertainty because it may mimic periapical pathology and result in possible endodontic mismanagement (35,36).

To date, the present study is the only study investigating CS and its ACs in a South African population. The only other African study to investigate CS was conducted in the Egyptian population (29). Therefore, the results of the present study represent novel findings with clinical importance to local practitioners. Furthermore, the results of this study serve to expand the existing body of literature on CS globally.

7.1 Retrospective analysis of CBCT scans

Modern dental treatment has seen a rise in the use of CBCT due to technological advancements resulting in improved scan quality, cost efficiency, and reduced radiation exposure (39). A recent review of the literature concluded CBCT scans to be the best modality for the evaluation of CS (8). Early studies investigated the course of CS by dissection of fresh cadaver heads and macerated skulls, however, these studies did not investigate the ACs of CS (17,18). All studies investigating the ACs of CS have implemented the retrospective analysis of CBCT scans as the study methodology (5–7,19,26–28,30–32,40). To date, no other method of investigation has been used. The present study implemented the use of retrospective CBCT analysis to investigate CS and its ACs as scans were readily available, and the methodology proved cost-effective and clinically applicable. Furthermore, this methodology represented the gold standard of CS evaluation (8). To observe greater detail surrounding the ACs of CS, a future study might implement the use of micro-CT scans of macerated skulls.

7.2 Prevalence, sidedness, and diameter of canalis sinuosus

Prevalence:

The vast majority (99.6%) of the subpopulation attending the Pretoria Oral and Dental Hospital presented with CS. The literature indicates that CS exists as a distinct anatomical entity rather than as an anatomical anomaly, with the reported prevalence of CS ranging from 66.5% to 100% between different population groups (1,2,19,26,27). The present study supports the assertion that CS exists as a distinct anatomical entity and suggests that the absence of CS should be considered abnormal.

Three possible explanations exist for the two cases in which CS was classified as absent in the present study. The first possibility was that CS was present, however its diameter measured less than 0.5mm, thereby disqualifying it from inclusion. The second explanation may be that the ASAN presented with an extra-osseous course thereby rendering CS non-existent and the ASAN undetectable on a CBCT scan. A future dissection study of cadaver heads, similar to that of Von Arx & Lozanoff, may help identify the possibility of an extra-osseous course of the ASAN (17). A third possible explanation may be that absent cases represent true anatomical anomalies in which the ASAN and CS does not exist. In these cases, alternative sources of innervation and vascular supply need to be investigated.

Sidedness:

The results of the present study demonstrated CS to be found bilaterally in 98.8% of cases. This finding was similar to the bilateral presence of CS recorded in the Brazilian, German, and Turkish populations at 99%, 100%, and 100% respectively (1,2,26). However, it contrasted with the low bilateral prevalence recorded in the Russian and another Brazilian population at 46% and 54% respectively (19,27). This difference may be attributed to the variation in methodologies between the studies rather than distinct anatomical differences between the population groups.

The present study implemented a methodology similar to Wanzeler *et al.*, Ghandourah *et al.*, and Gurler *et al.*, whereby CS and the ACs were considered as two distinct entities (1,2,26). However, the studies of Aoki *et al.* and Anatoly *et al.* made no such differentiation and considered both CS and the ACs as a single structure (19,27). This difference allowed the present study and the studies of Wanzeler *et al.*, Ghandourah *et al.*, and Gurler *et al.*, to record a higher bilateral presence of CS than that of Aoki *et al.* and Anatoly *et al.* as CS was still considered present, even in the absence of ACs (1,2,19,26,27).

The results of the present study indicate that, in general, CS should be regarded as present bilaterally across the South African population and that equal consideration should be given to left and right sides of the maxilla during pre-operative surgical planning and intervention.

Diameter:

Knowledge of the mean diameter of CS may assist clinicians to better plan invasive surgery in the anterior maxilla (8). According to a recent review of the literature, the average diameter of CS is accepted to be approximately 1mm, however, little evidence exists to support this claim as most studies reported the diameter of the ACs and not the CS itself (8). A study in the Turkish population used a minimum detection diameter of 0.75mm and determined the mean diameter of CS to be 1.37mm with a range of 0.75 – 2.25mm (2).

The present study implemented a minimum detection diameter of 0.50mm and determined the mean diameter of CS to be 1.08mm on both the right and left sides. Furthermore, the diameters of left and right CS were highly likely to be correlated within a single patient. This finding supports the view that equal surgical consideration should be given to CS bilaterally in the South African population.

The range of diameters recorded in a Turkish study (2) was similar to that of the present study (0.5mm – 2.39mm). The present study recorded a lower mean diameter of CS when compared to the Turkish study (1.37mm vs 1.08mm), but this may be attributable to the larger minimum detection diameter (0.75mm vs 0.50mm) implemented by the Turkish study (2).

As many studies focused on measuring ACs in lieu of CS (6,7,30) it is was difficult to find further comparative data regarding the diameter of CS. It was therefore useful to compare the diameters observed in the present study to those of other documented anatomical structures to contextualise the size of CS.

A multicentre study (conducted in Turkey, Cyprus, Spain, Lithuania, and Saudi-Arabia), as well as, an Iranian study retrospectively analysed CBCT scans of the mandible and reported the mean diameter of the lingual foramen to be 0.89mm (±0.40mm) and 1.12mm respectively (41,42). Similarly, a Swiss study determined the mean diameter of the lingual foramen to range between 0.90 – 1.20mm (43). The mean diameter of CS determined in the present study was therefore comparable to that of the lingual foramen (41–43). The risk of severe haemorrhage following damage to the lingual foramen during surgical intervention is well documented (3,41,42). As the size and contents of these two structures (i.e., CS and the lingual foramen) may be considered comparable, it is reasonable to infer that damage to CS may pose a similar risk of haemorrhage as damage to the lingual foramen.

A Serbian study determined the mean diameter of the inferior alveolar canal to be 2.6mm (44). This measurement was comparable to the largest diameter of CS found in the present study (2.39mm). Whilst CS does not routinely present at this diameter, a structure which may approach this size in certain cases is undoubtedly of clinical significance and may require extra precaution during surgical intervention.

Wanzeler *et al.* and Aoki *et al.* reported CS to maintain a constant diameter throughout its course (1,27). However, Aoki *et al.* did not provide measurements to substantiate this claim (27). Wanzeler *et al.* found differences between the mean diameter recorded at the canal's point of origin and terminal positions, however, these differences were not statistically significant (1). In the present study, the investigators observed substantial variability in the diameter of CS along its course. Accordingly, the present findings suggest that the diameter of CS is not constant throughout its course. However, no measurements were made to further support this observation. Further investigation may be beneficial to confirm whether CS presents a uniform diameter along its course. Future studies may additionally determine the mean diameter of CS across different population groups.

7.3 Effect of demographics on the prevalence and sidedness of canalis sinuosus

Discussion regarding the effect of demographics on the prevalence and sidedness of CS should be made in the context of two general observations found within the present study's population. Firstly, the majority of subjects in the present study were male, and secondly, a high number of young patients were represented.

The majority (61.6%) of subjects in the present study were male (n = 308/500). The high number of male patients represented in the present study reflected the Oro-facial trauma trends of the Pretoria Oral and Dental Hospital, which consist mainly of male subjects requiring CBCT scans to aid clinical management (45).

The present study recorded 49 subjects below the age of 20 all of which presented with a bilateral distribution of CS (n = 49/49; 100%). Only the studies of Orhan *et al.* and Shan *et al.* reported a larger number of patients below 20 years of age, recording 176 and 69 subjects respectively (5,30). Both studies included larger sample sizes with 1460 and 1007 subjects respectively, therefore a higher number of subjects across all ages groups could be expected when compared to the present study (5,30). All other studies reported significantly fewer subjects below the age of 20 years, irrespective of sample size (7,19,26,27,31). According to the South African National Census of 2011 the recorded median age of the South African population is 25 years of age (37). This classifies the South African population as an intermediate population relative to other countries -young populations record a median age <20 years, and old populations recording a median age >30 years (37). The high number of young patients (≤20 years) found in the present study is probably coincidental and not necessarily attributable to any inherent differences between other study populations.

Despite these two incidental observations regarding the population of the present study, the results showed demographics to have no significant influence on the presence or sidedness of CS.

No significant relationships regarding the prevalence or sidedness of CS and sex were found in the present study. This finding was consistent with studies conducted on the Brazilian, Belgian, Turkish, German, Chinese, Australian and Cypriot populations (1,3,5,7,26,28,30,32).

Age was also shown to have no significant effect on the presence or sidedness of CS in the present study. This finding was consistent with studies conducted in Brazilian, Turkish, Russian and Chinese populations (1,6,7,19,27,30,31).

The present study found population group to have no significant influence on the presence or sidedness of CS. No other study compared the effect of population group on the prevalence and sidedness of CS, but rather considered the entire population group under a single nationality. Thus, when comparing the results of the present study to other studies one should consider the entire sample as South African. A small number of subjects originating from neighbouring countries (but residing in South Africa) were included in the overall dataset, however these subjects were excluded when comparing the effect of population group in the present study.

The present study did not examine the effect of demographics on the prevalence or sidedness of the ACs of CS. However, this data is available and can be investigated if required. It is unlikely that demographics would play a significant role in the nature of the ACs in the South African population, as demographics did not play a significant role in the nature of CS. However, the possibility of significant differences between demographic factors and the nature of ACs cannot be dismissed without further investigation. Future studies may shed light on this topic.

The results of the present study indicated that the vast majority of South African patients, irrespective of sex, population group, and age should be regarded as routinely presenting with bilateral distribution of CS. This demonstrates the most probable anatomical configuration and provides the most cautious approach to surgical intervention in the area. Therefore, precautionary surgical measures should be followed for every patient.

7.4 Analysis of accessory canals

An important distinction made earlier in this discussion was the differentiation between CS and its ACs. The present study viewed CS and its ACs as two distinct entities. This distinction was however not observed by all authors and several previously elected to classify CS and its ACs as a single entity termed 'CS' (19,27,28). This has resulted in a lack of clarity and inconsistency in the methodology, design and reporting of results between studies regarding these structures. The prevalence of CS and its consistent anatomical features establishes this structure as a normal anatomical entity (3–7,19,26,27,29–31). Whereas, the results of the present study, and many others, demonstrate that the ACs of CS present with highly variable anatomy and are not always present (5–7,19,26–28,30–32). Therefore, the ACs of CS should be referred to as anatomical variations rather than normal anatomy. Therefore, referring to the combined structure of CS and its AC as a single, normal entity is a misnomer and may lead to further confusion among clinicians. To alleviate such confusion, it is recommended that a clear distinction be made between CS and its ACs in future investigations.

7.4.1 Prevalence and sidedness of the accessory canals

At least one AC was found in the majority (58.8%) of the sample of the present study. This prevalence was comparable to that of a Brazilian population at 52.1% (6). However, it was notably lower than those of Turkish, German and Cypriot populations recording prevalences of 70.8%, 67.6%, and 100% respectively (5,26,32). The prevalence of AC in the present study was much higher than those recorded in the Chinese population and two other Turkish populations with prevalences of 8.2%, 34.7%, and 36.9% respectively (7,30,31). The comparison of AC prevalence across different populations is summarised in table 14. Thus, the prevalence of the ACs of CS varies substantially between different populations, and ranges between 8.17 – 100% (5–7,19,26–28,30–32). No generalisation regarding the prevalence of the ACs of CS can therefore be made, and each population and patient should be assessed in isolation.

<u>Table 14:</u> **Summary of the prevalence of ACs of CS across different populations ranked in descending order.**

Study	Population	Sample size (n)	Prevalence of AC of CS (%)
Beyzade *et al.* (32)	Cypriot	91	100.0
Orhan et al. (5)	Turkish	1460	70.8
Ghandourah et al. (26)	German	201	67.6
The present study	**South African**	**500**	**58.8**
Machado et al. (6)	Brazilian	1000	52.1
Shan et al. (30)	Chinese	1007	36.9
Tomrukçu & Köse (7)	Turkish	326	34.7
Şalli & Öztürkmen (31)	Turkish	673	8.2

Several factors may be responsible for the substantial variation found between different studies. These factors can be divided into two categories; firstly, inherent differences between population groups, and secondly differences in study design.

The differences in the prevalence of ACs may represent true anatomical differences between different populations based on genetic, ethnic and geographical factors (3,46). Consequently, a variable need for pre-operative evaluation and surgical caution across different populations may exist. Alternatively, differences in the prevalence of ACs may have been created by inconsistencies in study design, including; differences in the minimum detection diameter, inclusion and exclusion criteria, CBCT machine and software used, voxel size, slice thickness, and the investigators experience (32). Currently no consistent method of AC identification has been described in the literature (5–7,19,26–28,30–32), therefore, the findings of each study should not be viewed without context, but based on the individual study's methodology.

The size of the minimum detection diameter used by different studies may have affected the prevalence of ACs recorded. Machado *et al.*, Aoki *et al.*, and Beyzade *et al.* did not implement a minimum detection diameter (6,27,32). These studies found a minority of ACs that measured greater than 1.0mm in diameter representing only 3.4%, 10.1%, and 20% of the recorded ACs respectively (6,27,32). Therefore, it can be expected that the greater the minimum detection diameter selected, the lower the recorded prevalence of ACs will be.

The decision of some authors to select a minimum detection diameter of 1.0mm for ACs may stem from the assumption that damage to a structure of this size may result in significant surgical complications. However, it has been reported that damage to structures less than 1mm in diameter, such as accessory lingual foramina, may still lead to significant intra-operative haemorrhage (3). The relationship between the severity and prevalence of surgical complications and the diameter of the ACs of CS has not yet been established. Thus, to promote safe clinical practice it should be assumed that all ACs of CS, regardless of diameter, may pose a potential risk of surgical complication.

Variations in the inclusion and exclusion criteria of different studies may furthermore have played a role in the recorded prevalence of ACs (32). The present study did not allow for the inclusion of pathological lesions, impactions, clefts, missing teeth, supernumeraries, radiographic artefacts, or implants. However, if other studies permitted the inclusion of any of these factors it may have affected the reported prevalence of ACs. Ferlin *et al.* demonstrated a significantly higher prevalence of ACs amongst CLP patients when compared to patients without CLP (33). The presence of impacted maxillary canines has been shown to have little effect on the prevalence of CS, however their effect on the prevalence of ACs has not been thoroughly investigated (2,5). Further research is needed to determine the effects of various other pathologies and conditions on the prevalence and structure of CS and its ACs. For example, the effect of tooth loss on the prevalence of CS and its ACs has yet to be investigated.

The technical quality of the CBCT scans included in each study may also have affected the prevalence of ACs recorded. The higher the technical quality of the CBCT scan, the more accurate the identification of ACs. Several factors may affect the technical quality of CBCT scans including; software, voxel size, slice thickness, field of view, and exposure parameters (7,28,32). Due to the diminutive nature of ACs it is suggested to use a small voxel size and thin slice thickness, as a large voxel size and larger slice thickness may prevent detection of ACs. To accommodate the large sample size of the present study, the investigators implemented a maximum voxel size of 400µm. This led to the inclusion of CBCT scans with a relatively low diagnostic resolution when compared to other studies (6,7,26–28,30–32). The low resolution of these scans may have contributed towards the relatively low prevalence of ACs observed in the present study (5,26,32). In future, it is recommended that only high quality CBCT scans with lower resolution (minimum voxel size of 200µm), minimum slice thickness, and limited field of view should be used for the identification of ACs of CS.

Beyzade *et al.* reported that the experience and anatomical knowledge of the investigator may play a role in the reported prevalence of ACs – particularly in studies with smaller sample sizes (32). An inexperienced investigator may under-represent the number of ACs in a sample due to their inability to identify the structure. Alternatively, an inexperienced investigator may also over-represent the prevalence of ACs by incorrectly identifying other anatomical structures as ACs (such as nutrient canals, bony trabeculae or widened periodontal ligament as demonstrated in figure 18). Despite this assertion, most studies recorded high agreement levels between multiple investigators with significant experience in interpreting CBCT scans (1,3,5,28,30–32). Therefore, this factor was unlikely to significantly affect the results of different studies. However, the inaccurate identification of CS and its ACs remains a concern when considering the clinical assessment of CBCT by individual practitioners. This was demonstrated by Lopes-Santos *et al.*, who found that the majority of dental practitioners were unable to identity CS and its ACs on CBCT scans, irrespective of the practitioner's age or experience in the field of dentistry (34).

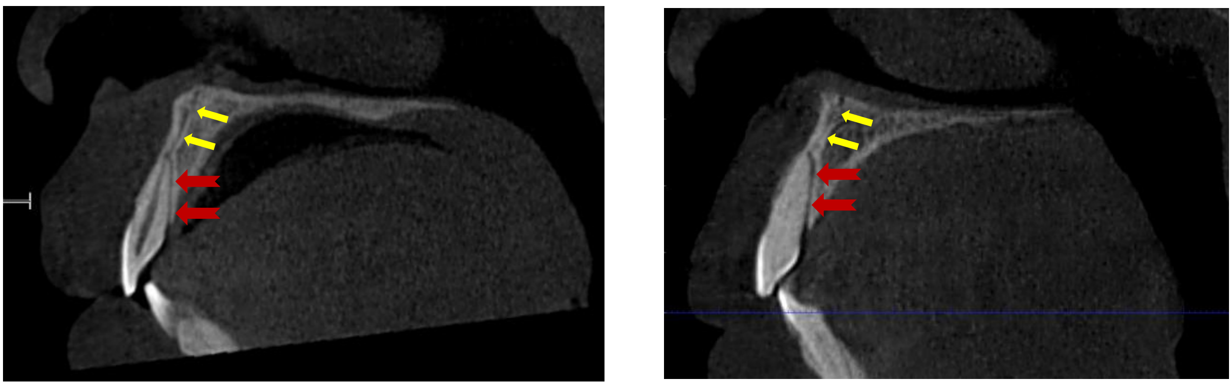

Figure 18: Two different examples of nutrient canals extending from CS to the apex of the central incisors on a sagittal view. Nutrient canals indicated by yellow arrows. Note the widened periodontal ligament (indicated by red arrows) which may create diagnostic confusion among inexperienced practitioners.

When considering the differences between population groups and study design it may be useful to interpret the studies of Orhan *et al.*, Tomrukçu & Köse, and Şalli & Öztürkmen (5,7,31). All three studies examined the prevalence of ACs of CS in the Turkish population and demonstrated similar study designs (including minimum detection diameter, inclusion and exclusion criteria, voxel size, slice thickness, and the investigators experience) but reported vastly different results. The prevalences of ACs in these studies ranged between 8.17% and 70.8% (5,7,31). The results of these three studies are summarised in table 15.

<u>Table 15:</u> **Summary of the differences in the recorded prevalence of ACs of CS in three different Turkish studies.**

Study	Population	Sample size (n)	Prevalence of AC of CS (%)
Orhan et al. (5)	Turkish	1460	70.8
Şalli & Öztürkmen (31)	Turkish	673	8.2
Tomrukçu & Köse (7)	Turkish	326	34.7

These findings indicate that the population group and study design may not necessarily play a profound role in the recorded prevalence of ACs, and that variation may still be observed within similar populations. This emphasises the need for extensive pre-operative evaluation of the anterior maxilla prior to surgical intervention, as the clinician cannot rely solely on a low reported prevalence of ACs in a given population. Accordingly, the clinician must evaluate patients individually and, in this way, uphold the principle of non-maleficence.

Although the sidedness and distribution of the ACs of CS have previously been investigated these findings have not frequently been reported (7). The results of the present study show that in cases where ACs were detected 42.9% occurred bilaterally and 57.1% occurred unilaterally. This was comparable to the distribution of ACs determined by Tomrukçu & Köse who reported a bilateral distribution of ACs in 49% of cases and a unilateral distribution in 51% (7). This differed from the study of Beyzade *et al.* who recorded a bilateral distribution of ACs in 94.5% of cases and a unilateral distribution in 5.5% (32). These findings are summarised in table 16. A paucity of evidence exists to conclude whether the ACs of CS commonly occur unilaterally or bilaterally, however, available findings seem to indicate no difference in the prevalence of a bilateral or unilateral distribution.

Table 16: **Summary of the differences in the distribution of ACs of CS across different studies.**

Study	Population	Prevalence of bilateral ACs (%)	Prevalence of unilateral ACs (%)
Tomrukçu & Köse (7)	Turkish	49.0	51.0
Beyzade *et al.* (32)	Cypriot	94.5	5.5
The present study	**South African**	**42.9**	**57.1**

The present study demonstrated no preference for sidedness in the South African population with 49.9% of all ACs presenting on the left and the other 50.1% presenting on the right. This was similar to the findings of Tomrukçu & Köse who found 47% of all ACs presented on the left and the remaining 53% (n = 114/214) on the right (7). It is therefore reasonable to infer that the ACs of CS do not necessarily present in bilateral pairs and should be considered as individual entities. Accordingly, oral health practitioners should not necessarily infer symmetry when examining patients for ACs and should examine both right- and left- hand sides of CBCT scans independently.

7.4.2 Diameters of the accessory canals

The results of the present study demonstrated a mean diameter of the ACs of 0.86mm (±0.28) on the left and 0.87mm (±0.27) on the right. The largest AC was recorded at 1.52mm. The present study used a minimum detection diameter of 0.50mm and measured the AC within its course away from its foramen.

The mean diameter of ACs recorded in the present study was smaller than the mean diameters recorded by Tomrukçu & Köse, Machado *et al.*, and Shan *et al.* in the Turkish, Brazilian and Chinese populations respectively (6,7,30). Tomrukçu & Köse reported a mean diameter of the ACs of CS at 1.07mm (±0.35) using a minimum detection diameter at 0.50mm and measuring the AC of CS within its course (7).

Machado *et al.* and Shan *et al.* both implemented a minimum detection diameter of 1.0mm and recorded mean diameters of the ACs of CS at 1.19mm and 1.1mm respectively (6,30). A comparison of the findings of these studies can be found in table 17. The smaller mean diameter of the ACs recorded in the present study can be attributed to the smaller minimum detection diameter used when compared to that of Machado *et al.* and Shan *et al.* (6,30). Furthermore, the studies of Machado *et al.* and Aoki *et al.* demonstrated that the majority of ACs of CS (80% and 96.6% respectively) possessed a diameter less than 1.0mm (6,27). Therefore, it was favourable to use a smaller minimum detection diameter to determine the mean diameter of these canals, favouring the methodology of the present study.

<u>Table 17:</u> **Comparison of the measurements of the AC of CS between different population groups.**

Study	Population	Minimum measurement diameter (mm)	Average diameter of AC of CS (mm)	Standard deviation (mm)	Range (mm)
Machado *et al.* (6)	Brazilian	1.0	1.19	0.22	1.00 - 2.58
Shan *et al.* (30)	Chinese	1.0	1.10	0.10	1.00 - 2.10
Tomrukçu & Köse (7)	Turkish	0.5	1.07	0.35	0.53 - 2.72
Present Study	**South African**	**0.5**	**0.86 / 0.87**	**0.28 / 0.27**	**0.50 - 1.52**

The observations of Von Arx *et al.* and the findings of Tomrukçu & Köse indicated that the foramen of an AC was wider than the internal width of the canal (4,7). Tomrukçu & Köse demonstrated that the mean diameter of the foramen measured 0.23mm more than the mean internal width of the ACs (7). The present study incorporated this observation into its methodology by measuring the internal width of the AC rather than the foramen to obtain a more accurate representation of the ACs true width.

Nevertheless, the present study recorded a mean diameter of less than 1.0mm for ACs, which was noticeably smaller than other studies (6,7,30), despite differences in study design. This finding may represent inaccuracy during the measurement of ACs or it could represent true anatomical differences due to genetic, ethnic and geographical variations (3,46). To validate the accuracy of the measurements of the present study, it is recommended that an external party repeat the measurements using the same methodology.

Yeap *et al.* determined a substantial difference (0.37mm) between the widest and narrowest mean diameters of CS and its ACs in the Australian population (28). This finding was significant as it demonstrated how the diameters of the AC may vary within a single canal, between patients, and between studies with different methodologies. Furthermore, the 0.37mm difference in canal width recorded by Yeap *et al.* (28) was larger than the standard deviation of the ACs recorded by Machado *et al.*, Shan *et al.*, Tomrukçu & Köse, (6,7,30) and the present study.

The exact measurements of the ACs recorded by each study is probably of limited practical use, due to inaccuracy and imprecision associated with the study design and data collection. The nature of CBCT scan acquisition and analysis creates opportunity for multiple technical errors and measurement inaccuracy by the investigator. Errors in CBCT scan acquisition, such as; patient movement, patient breathing, increased voxel size, decreased slice thickness, image hardening and scattered radiation may affect the accuracy of the radiographic image produced and, in turn, the accuracy of the measurements recorded (47). Errors in measurement by the investigator may include; a lack of precision, operator fatigue, misidentification, missed anatomy and inaccurate identification of the size and extent of the structure. In isolation these errors may seem negligible but when recording such precise measurements (0.01mm), the cumulative effect of these errors cannot be ignored.

For these reasons, it may be more useful to interpret the mean AC diameter as a range of measurements. This may be more accurate than considering the measurement in isolation, and interpreting this as an absolute value. For clinical purposes the practitioner should understand that the ACs of CS in the South African population most commonly measured within the range of 0.58mm and 1.14mm on both left and right sides. Furthermore, the clinician should be able to use this information to aid in the identification of ACs pre-operatively.

7.4.3 Course of the accessory canals

The descriptive course of the ACs of CS has been poorly documented in the literature, with only the study of Tomrukçu & Köse documenting the prevalence of each AC configuration (7).

Oliveira-Santos *et al.* and Von Arx *et al.* were the first to describe the course of ACs in the anterior maxilla (3,4). However, both studies did not exclusively examine the ACs of CS, but rather any additional canals present in the maxilla. Oliveira-Santos *et al.* and Von Arx *et al.* agreed upon one configuration for the ACs of CS, which was described as communicating directly with CS and curving inferiorly towards the alveolar bone (3,4). The other configurations of the ACs described by Oliveira-Santos *et al.* and Von Arx *et al.* were not exclusively attributed to CS (3,4).

Tomrukçu & Köse used the work of Von Arx *et al.* to classify the ACs of CS into three categories termed; 'curved', 'vertical' and 'Y-shaped' (4,7). The 'curved' pattern is described above. The 'vertical' pattern occupied a vertical direction from the medial aspect of the nasal aperture superiorly towards the anterior palate inferiorly (7). Finally, the 'Y-shaped' pattern emerged with one branch originating from CS and the other originating from the medial aspect of the nasal aperture (7). Tomrukçu & Köse reported that the majority (69.2%) of the ACs of CS occupied a curved course, while 26.2% occupied the vertical course, and the remaining 4.7% occupied the Y-shaped course (7). Marzook *et al.* was the only study to report ACs of CS which travelled posteriorly (29). The prevalence of this finding was however not recorded.

The present study used the work of Oliveira-Santos *et al.*, Von Arx *et al.*, and Marzook *et al.* to create a classification system describing the course of the ACs of CS (3,4,29). The course of the ACs were classified into five distinct patterns; straight vertical, curved medially, curved laterally, curved distally, and other (Figures 11 – 15). In the present study, all ACs progressed through the maxilla from a superior point of origin to an inferior point of termination. The present study did not record a single instance of the Y-shaped pattern described by Oliveira-Santos *et al.* and Von Arx *et al.* (3,4), however documented a number of ACs which terminated posteriorly.

Yeap *et al.* demonstrated that the anatomy of the ACs of CS is complex in nature and may display cases of convergence, bifurcation and trifurcation (28). The present study did not record these features. During data collection for the present study, it was noted that it was easier to identify ACs of CS which possessed a ‘straight vertical’ and ‘curved distal’ course in the sagittal plane as demonstrated in figures 11 and 14. ACs which presented as ‘curved medially’ and ‘curved laterally’ were more readily identified in coronal planes as demonstrated in figures 12 and 13. This observation, and the fact that ACs can present with complex anatomy, reiterates the need to evaluate a high quality CBCT scans in all three planes prior to surgical intervention (28,40).

It is important to determine the course of an AC of CS as it may affect the depth and orientation to which surgical intervention may safely take place. Accordingly, when an AC of CS is present in the region of surgical interest the practitioner should note the course of the AC during pre-operative surgical planning to identify the regions least likely to cause damage during surgical intervention.

7.4.4 Terminal positions of the accessory canals of canalis sinuosus

It is important for clinicians to have an accurate understanding of the distribution of the terminal positions of the ACs of CS as it represents the most superficial aspect of the structure and therefore may represent the most vulnerable aspect of CS during surgical intervention. To aid the understanding clinicians, the terminal positions of the AC of CS detected in the present study are described comprehensively in table format and visually by means of a diagram.

Machado et al. and Anatoly et al. found that the majority of ACs terminated in the anterior palatal region of the maxilla, representing 91.1% and 76% of cases respectively (6,19). Both studies found that a minority of ACs terminated in a buccal position (representing 5.1% and 12% of cases respectively), while the remaining 3.8% and 12% of cases terminated in a transversal position (6,19). The present study demonstrated the same pattern of distribution as the studies of Machado et al. and Anatoly et al. with the majority of ACs observed in the anterior palatal region of the maxilla, and a minority of cases found in buccal and transversal positions (6,19). However, the distribution of the ACs in each anatomical region in the present study differed notably from the aforementioned studies. When compared to the previous studies, the present study found fewer ACs occupied a palatal position, while a greater percentage of ACs occupied buccal and transversal terminal positions, representing 57.2%, 21.7%, and 10.5% of all cases respectively. Table 18 provides a summary of these findings.

Table 18: **Comparison between populations of the different regions of termination of the ACs of CS**

Study	Population	Prevalence of ACs terminating in each region (%)		
		Palatal	Buccal	Transversal
Machado et al. (6)	Brazilian	91.1	5.1	3.8
Anatoly et al. (19)	Russian	76.0	12.0	12.0
Present Study	**South African**	**57.2**	**21.7**	**10.5**

Machado et al. and Anatoly et al. did not differentiate between ACs terminating in the anterior palate, mid-palatal region, or near the incisive foramen, but rather regarded all three regions as one (6,19). It was therefore expected that a higher percentage of the ACs in these studies would be classified as terminating in the anterior palatal region when compared with the present study. The present study separated these anatomical locations for greater descriptive accuracy. If the present study followed exactly the same classification as Machado et al. and Anatoly et al., the prevalence of ACs terminating in the anterior palate would have risen to 67.8% (6,19).

When examining the individual points of termination of the ACs found in the present study it was interesting to observe that the four most common points of termination were the same across both left and right sides. This indicated that sidedness had little effect on the distribution of the ACs in the South African population. This finding is favorable in a clinical setting as it may be easier for the clinician to acknowledge which regions of surgical interest occupy a higher risk of neurovascular damage.

When bilateral positions were considered, the three most common points of AC termination in the present study occurred; palatal of the central incisors, buccal of the interproximal region between the central incisors, and palatal of the lateral incisors. This was similar to the findings of Orhan *et al.*, Ghandourah *et al.*, Yeap *et al.*, and Aoki *et al.* who found the most common position of termination of the ACs to be in the region of the central incisors (5,26–28). Furthermore, in the present study the third most common region of termination of the ACs occurred palatal of the lateral incisors which was similar to the findings of Machado et al., Şalli & Öztürkmen, Tomrukçu & Köse, Anatoly *et al.*, and Beyzade *et al.* who indicated that the region of the lateral incisors was the most common point of termination (6,7,19,31,32). A significant finding of the present study was the relatively high percentage of ACs terminating in a buccal position. This finding may indicate a higher risk of neurovascular damage during surgical intervention involving manipulation of the buccal aspect of the anterior maxilla in the sample population of the present study.

The percentage of ACs terminating in each individual point of termination was notably lower in the present study than other studies. This may be attributed to the increased number of anatomical locations used by the present study to classify the point of AC termination when compared to other studies. By way of example, the most common point of termination recorded in the present study occurred palatal of the central incisors but only represents 19.3% (n = 103/535) of all ACs, whereas the studies of

Ghandourah *et al.*, Yeap *et al.*, and Aoki *et al.* recorded the same point of termination but observed 41.3%, 41.3%, and 44.4% of all ACs to terminate at this point (26–28).

When palatal, buccal, transversal and interproximal regions around the central incisors were considered together it represented 49.3% (*n* = 264/535) of all ACs detected in the present study. Similarly, when all the points of termination surrounding the lateral incisors were considered it represented 23.2% (*n* = 124/535) of all ACs. If all the termination points surrounding the central and lateral incisors were considered together it represented 69.9% (*n* = 374/535) of all ACs detected in this study. This finding demonstrates that meticulous pre-operative examination on a high quality CBCT and extra surgical precaution needs to be implemented during surgical intervention in the region of the central and lateral incisors due to high prevalence of ACs of CS found in this region.

In total, 69 different terminal positions of ACs of CS were recorded in the present study. This demonstrated that the anatomy of the ACs was highly variable in nature and a unique approach to each patient should be implemented by clinicians. Figures 16 & 17 illustrate the terminal positions of the ACs observed in the present study and may serve as a visual aid to clinicians planning surgical intervention in the South African population. Figures 16 & 17 may be more clinically applicable and user-friendly to clinicians who respond well to visual guides, while tables 12 & 13 provide comprehensive information regarding the terminal positions of the ACs.

Figure 16 illustrates five chief regions of AC termination including; buccal, transversal, palatal, near the incisive foramen, and mid-palatal region. Figure 17 represents a detailed illustration of the ACs terminating in the mid-palatal region. Figure 16 combines the work of Machado *et al.* and Oliveira-Santos *et al.* while adjusting key aspects to represent a novel and clinically applicable diagram (3,6). Figure 16 displays the positions of AC termination bilaterally [similar to Machado *et al.* (6)], while also referencing AC termination relative to the incisive foramen [similar to Oliveira-Santos *et al.* (3)]. However, figure 16 is unique in that it extends the area of interest to the second maxillary premolars, demarcates ACs terminating in the same anatomical region from different origin (left or right CS), and displays the ACs which terminate in transversal positions in an interproximal position diagrammatically. Figure 17 is a novel illustration as no other study has documented the precise location of the ACs which terminated in the mid-palatal region

7.5 Recommendations

The findings of the present study indicate that meticulous examination of a high quality CBCT scan prior to surgical intervention of the anterior maxilla is critical to avoid intra-operative damage to CS and its ACs. Oral health care practitioners should possess intimate knowledge of clinically relevant anatomy and should be well trained in the interpretation of CBCT scans.

Another recommendation of the present study is to discard the term 'canalis sinuosus' in future studies and to instead refer to the structure as the 'anterior superior alveolar nerve canal'. The apparent lack of knowledge among oral health care practitioners regarding CS may reflect an error in nomenclature rather than a true deficit in anatomical knowledge. However, to comprehensively address the issue of inadequate knowledge among oral health care practitioners regarding CS anatomical texts, tertiary institutions, and continuous learning programs should impart increased detail regarding the morphology, localization, and variability of the structure. Ultimately, it is the responsibility of the individual practitioner to uphold the principals of beneficence and non-maleficence during surgical intervention by exercising appropriate caution through adequate anatomical knowledge and pre-operative assessment.

For future studies, it is recommended that stricter parameters be imposed on the technical quality of the CBCT scans selected for analysis. A maximum voxel size of 200µm would improve the quality of the scans and therefore eliminate diagnostic uncertainty. This adjustment to the methodology of the present study may improve the reliability of the findings.

7.6 Limitations

Although the methodology of the present study was consistent with many previous studies it was not exempt from limitations. The limitations of the present study may have included; a large voxel size, large slice thickness, measurement inaccuracy, examiner bias and a lack of repetition during data capture.

The maximum voxel size accepted for the present study was 400µm, thus less detail was available in the CBCT scans compared to other investigations which implemented a maximum voxel size below 250µm (6,7,26–28,30–32). The reduced clarity of the CBCT scans included in the present study may have hindered the detection of CS and its ACs. Furthermore, the maximum slice thickness used in the present study was 400µm while the minimum detection diameter was set at 0.50mm (500µm). As these two measurements were similar in size it was possible that some ACs remained undetected. Consequently, the true prevalence of ACs within the South African population may be slightly higher than the prevalence recorded in the present study.

The diminutive size of CS and its ACs, the technical errors associated with CBCT scans, and the human error associated with measurement leaves the present study susceptible to measurement inaccuracy. As discussed previously the individual measurements recorded in the present study were unlikely to represent absolute values, however, the broader understanding of these measurements was still of value.

Examiner bias refers to the phenomenon in which individual examiners view outcomes in a particular way, typically leniently or stringently (48). As a single examiner was responsible for the majority of the CBCT scan analysis in the present study the personal preferences of this investigator may be reflected in the results. However, calibration between the investigators reduced the impact of this phenomenon.

During data capture, all measurements and observations for CS were repeated by the investigator on two separate occasions. This improved the reliability of these findings as there were opportunities to validate or discard previous findings. In contrast to this, the measurements, and observations regarding the ACs were only recorded in one instance. This decreased the reliability of these results as these particular findings were not confirmed during a second examination.

8. Conclusion

The following conclusions can be drawn from the South African population investigated in the present study:

- CBCT proved a reliable and efficient modality to view CS and its ACs.
- CS was found in nearly all subjects (99%) and was commonly observed bilaterally (98%).
- The mean diameter of the CS was 1.08mm.
- CS should be regarded as a distinct anatomical entity.
- Sex, population group, and age demonstrated no significant effect on the prevalence or sidedness of CS.
- Many patients presented with at least one AC (58% of subjects), the anatomy of which was highly variable and inconsistent.
- The mean diameter of the ACs measured less than 1.00mm.
- ACs present as individual entities rather than bilateral pairs.
- The majority of the ACs of CS presented with a straight vertical configuration (72% of cases).
- The most common point of AC termination occurred palatal of the maxillary central incisors (19% of cases).
- Meticulous examination of a high quality CBCT scan prior to surgical intervention of the anterior maxilla is critical to avoid intra-operative damage of CS and its ACs.

9. References

1. Wanzeler A, Marinho C, Junior S, Manzi F, Tuji F. Anatomical study of the canalis sinuosus in 100 cone beam computed tomography examinations. Oral Maxillofac Surg. 2015;19(1):49–53.

2. Gurler G, Delilbasi C, Ogut EE, Aydin K, Sakul U. Evaluation of the morphology of the canalis sinuosus using cone-beam computed tomography in patients with maxillary impacted canines. Imaging Sci Dent. 2017;47(2):69–74.

3. de Oliveira-santos C, Rubira-bullen IRF, Monteiro SAC, Leo JE, Jacobs R. Neurovascular anatomical variations in the anterior palate observed on CBCT images. Clin Oral Implant Res. 2012;24(9):1044–9.

4. Von Arx T, Lozanoff S, Sendi P, Bornstein MM. Assessment of bone channels other than the nasopalatine canal in the anterior maxilla using limited cone beam computed tomography. Surg Radiol Anat. 2013;35(9):783–90.

5. Orhan K, Gorurgoz C, Akyol M, Ozarslanturk S, Avsever H. An anatomical variant: evaluation of accessory canals of the canalis sinuosus using cone beam computed tomography. Folia Morphol. 2018;77(3):551–7.

6. Machado V, Chrcanovic B, Felippe M, Manhães Júnior L, de Carvalho P. Assessment of accessory canals of the canalis sinuosus: a study of 1000 cone beam computed tomography examinations. Int J Oral Maxillofac Surg. 2016;45(12):1586–91.

7. Tomrukçu DN, Köse TE. Assesment of accessory branches of canalis sinuosus on CBCT images. Med Oral Patol Oral Cir Bucal. 2020;25(1):124–30.

8. Ferlin R, Pagin BSC, Yaedu RY. Canalis sinuosus: a systematic review of the literature. Oral Surg Oral Med Oral Pathol Oral Radiol. 2019;127(6):545–51.

9. Jones FW. The Anterior Superior Alveolar Nerve and Vessels. J Anat. 1939;73(4):583–591.

10. Shintaku WH, Ferreira CF, Venturin J de S. Invasion of the canalis sinuosus by dental implants: a report of 3 cases. Imaging Sci Dent. 2020;50(4):353–7.

11. Volberg R, Mordanov O. Canalis sinuosus damage after immediate dental implant placement in the esthetic zone. Case Rep Dent. 2019;16:3462794.

12. Arruda JA, Silva P, Silva L, Álvares P, Silva L, Zavanelli R, et al. Dental implant in the canalis sinuosus: a case report and review of the literature. Case Rep Dent. 2017;4810123.

13. Mccrea SJJ. Aberrations causing neurovascular damage in the anterior maxilla during dental implant placement. Case Rep Dent. 2017;5969643.

14. Rusu MC, Iacov-Crăiţoiu MM, Săndulescu M, Cârstocea L, Stana DM. Constant features of the adult maxillary bone in the site of the premaxillary suture: the sutura notha, macalister's foramina, parinaud's canal, and the second angle of the canalis sinuosus of wood jones. Rom J Morphol Embryol. 2019;60(4):1097–103.

15. Jacobs C, Greyling L, Meiring J. Embryology for the Health Sciences Student. 1st ed. Pretoria: UPrinters; 2006. 55–71 p.

16. Vacher C, Sakka M, Dauge M. Incisive suture (fissure) in the human fetus: radiographic and histologic study. Cleft Palate Craniofac J. 2001;38(4):330–6.

17. Von Arx T, Lozanoff S. Anterior superior alveolar nerve (ASAN). Swiss Dent J. 2015;125(11):1202–9.

18. Olenczak J, Hui-Chou H, Aguila D, Shaeffer C, Dellon A, Manson P. Posttraumatic Midface Pain: clinical significance of the anterior superior alveolar nerve and canalis sinuosus. Ann Plast Surg. 2015;75(5):543–7.

19. Anatoly A, Sedov Y, Gvozdikova E, Mordanov O, Kruchinina L, Avanesov K, et al. Radiological and morphometric features of canalis sinuosus in russian population: cone-beam computed tomography study. Int J Dent. 2019;(16):2453469.

20. Sedov YG, Anatoly M, Zurnacheva DD, Mustafaeva RS, Blokhina A V. Visualization features of canalis sinuosus with cone beam computed tomography. Indian J Dent Res. 2019;30(5):656–60.

21. Gray H. Anatomy of the Human Body [Internet] 1. Philadelphia: Lea & Febiger;

1918. 5e. The Trigeminal Nerve, paragraph 32.

22. Fitzgerald BYMJT. The occurrence of a middle superior alveolar nerve in man. J Anat. 1956;90(4):520–2.

23. Robinson S, Wormald P. Patterns of innervation of the anterior maxilla: a cadaver study with relevance to canine fossa puncture of the maxillary sinus. Laryngoscope. 2005;115(10):1785–8.

24. Velasco I, Soto R. Anterior and middle superior alveolar nerve block for anesthesia of maxillary teeth using conventional syringe. Dent Res J (Isfahan). 2012;9(5):535.

25. Gray H. Anatomy of the Human Body [Internet] 2. Philadelphia: Lea & Febiger; 1918. 3a2. The External Carotid Artery, paragraph 79.

26. Ghandourah A, Rashad A, Heiland M, Hamzi B, Friedrich R. Cone-beam tomographic analysis of canalis sinuosus accessory intraosseous canals in the maxillah. Ger Med Sci. 2017;19(15):20.

27. Aoki R, Massuda M, Zenni TVL, Fernandes KS. Canalis sinuosus: anatomical variation or structure? Surg Radiol Anat. 2020;42(1):69–74.

28. Yeap CW, Danh D, Chan J, Parashos P. Examination of canalis sinuosus using cone beam computed tomography in an australian population. Aust Dent J. 2022;67(3):249-261.

29. Marzook AHAM, Elgendy AA, Darweesh FA. New accessory palatine canals and foramina in cone beam computed tomography. Folia Morphol. 2020;(23).

30. Shan T, Qu Y, Huang X, Gu L. Cone beam computed tomography analysis of accessory canals of the canalis sinuosus: a prevalent but often overlooked anatomical variation in the anterior maxilla. J Prosthet Dent. 2021;126(4):560-568.

31. Şalli GA, Öztürkmen Z. Evaluation of location of canalis sinuosus in the maxilla using cone beam computed tomography. Balk J Dent Med. 2021;25(1):7–12.

32. Beyzade Z, Yılmaz HG, Ünsal G, Çaygür-Yoran A. Prevalence, radiographic

features and clinical relevancy of accessory canals of the canalis sinuosus in cypriot population: a retrospective cone-beam computed tomography (CBCT) Study. Medicina. 2022;58(7).

33. Ferlin R, Pagin BSC, Yaedú RYF. Evaluation of canalis sinuosus in individuals with cleft lip and palate: a cross-sectional study using cone beam computed tomography. Oral Maxillofac Surg. 2021;25(3):337–43.

34. Lopes-Santos G, Salzedas LMP, Bernabé DG, Ikuta CRS, Miyahara GI, Tjioe KC. Assessment of the knowledge of canalis sinuosus amongst dentists and dental students: an online-based cross-sectional study. Eur J Dent Educ. 2022;26(3):488–98.

35. Shah PN, Arora A V., Kapoor S V. Accessory branch of canalis sinuosus mimicking external root resorption: a diagnostic dilemma. J Conserv Dent. 2017;20(6):479–81.

36. Shelley A, Rushton V, Horner K. Canalis sinuosus mimicking a periapical inflammatory lesion. Br Dent J. 1999;18(8):378–9.

37. Satitistics South Africa. Census 2011. Pretoria; 2012. Available from: https://www.statssa.gov.za/publications/P03014/P030142011.pdf

38. Breckenridge K. The Book of Life: The South African population register and the invention of racial descent, 1950-1980. Sci Electron Libr Online South Africa. 2014;40(1):225–40.

39. Ahmad M, Jenny J, Downie M. Application of cone beam computed tomography in oral and maxillofacial surgery. Aust Dent J. 2012;57:82–94.

40. Junior LRCM, Villaça-Carvalho MFL, de Moraes MEL, Lopes SLPDC, Silva MBF, Junqueira JLC. Location and classification of canalis sinuosus for cone beam computed tomography: avoiding misdiagnosis. Braz Oral Res. 2016;30(1):1–9.

41. Yildirim YD, Güncü GN, Galindo-Moreno P, Velasco-Torres M, Juodzbalys G, Kubilius M, et al. Evaluation of mandibular lingual foramina related to dental implant treatment with computerized tomography: a multicenter clinical study.

Implant Dent. 2014;23(1):57–63.

42. Sheikhi M, Mosavat F, Ahmadi A. Assessing the anatomical variations of lingual foramen and its bony canals with CBCT taken from 102 patients in Isfahan. Dent Res J. 2012;9(Suppl 1):S45-51.

43. Von Arx T, Matter D, Buser D, Bornstein MM. Evaluation of location and dimensions of lingual foramina using limited cone-beam computed tomography. J Oral Maxillofac Surg. 2011;69(11):2777–85.

44. Obradovic O, Todorovic L, Pesic V, Pejkovic B V V. Morphometric analysis of mandibular canal: clinical aspects. Bull Gr Int Rech Sci Stomatol Odontol. 1993;36(3–4):109–13.

45. Roode GJ, van Wyk PJ, Botha SJ. Mandibular fractures: an epidemiological survey at the Oral and Dental Hospital, Pretoria. SADJ. 2007;62(6):6–9.

46. Liang X, Jacobs R, Corpas LS, Semal P, Lambrichts I. Chronologic and geographic variability of neurovascular structures in the human mandible. Forensic Sci Int. 2009;190(1–3):24–32.

47. Makins SR. Artifacts interfering with interpretation of cone beam computed tomography images. Dent Clin North Am. 2014;58(3):485–95.

48. Schleicher I, Leitner K, Juenger J, Moeltner A, Ruesseler M, Bender B, et al. Examiner effect on the objective structured clinical exam - a study at five medical schools. BMC Med Educ. 2017;17(1):1–7.

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Figure 4: Schematic illustration of the three variations of ACs in the anterior maxilla described by Von Arx *et al.*	11	Von Arx T, Lozanoff S, Sendi P, Bornstein MM. Assessment of bone channels other than the nasopalatine canal in the anterior maxilla using limited cone beam computed tomography. Surg Radiol Anat. 2013;35(9):783–90.	2013 Springer-Verlag France	Yes	Yes 06/10/2022	Yes 06/10/2022 License number: 5403120183949
Figure 6: 3D rendition of the midface highlighting the course of CS giving off two ACs bilaterally.	14	Machado V, Chrcanovic B, Felippe M, Manhães Júnior L, de Carvalho P. Assessment of accessory canals of the canalis sinuosus : a study of 1000 cone beam computed tomography examinations. Int J Oral Maxillofac Surg. 2016;45(12):1586–91.	2016 International Association of Oral and Maxillofacial Surgeons. Published by Elsevier Ltd.	Yes	Yes 06/10/2022	Yes 06/10/2022 License number: 5403110196466
Figure 7: Diagram depicting the local termination of the ACs of CS	20	Machado V, Chrcanovic B, Felippe M, Manhães Júnior L, de Carvalho P. Assessment of accessory canals of the canalis sinuosus : a study of 1000 cone	2016 International Association of Oral and	Yes	Yes 06/10/2022	Yes 06/10/2022

described by Machado *et al.* (6).		beam computed tomography examinations. Int J Oral Maxillofac Surg. 2016;45(12):1586–91.	Maxillofacial Surgeons. Published by Elsevier Ltd.			License number: 5403110196466

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Figure	Page number	Source	Copy right owner	Open access (yes/no)	Permission required (yes/no)
Figure 1: Schematic illustration of the rudimentary course of CS in the maxilla.	4	Mccrea SJJ. Aberrations Causing Neurovascular Damage in the Anterior Maxilla during Dental Implant Placement. Case Rep Dent. 2017;5969643.	2017 Shane J. J. McCrea.	Yes	No
Figure 2: Schematic illustration of the measured course of CS.	5	Von Arx T, Lozanoff S. Anterior superior alveolar nerve (ASAN). Swiss Dent J. 2015;125(11):1202–9.	2015 Swiss Dental Journal, SSO	Yes	No
Figure 3: Rusu *et al.'s* 3D renderings of the anterior view of the midface.	6	Rusu MC, Iacov-Crăiţoiu MM, Săndulescu M, Cârstocea L, Stana DM. Constant features of the adult maxillary bone in the site of the premaxillary suture: The sutura notha, macalister's foramina, parinaud's canal, and the second angle of the canalis sinuosus of wood jones. Rom J Morphol Embryol. 2019;60(4):1097–103.	2019 Romanian Journal of Morphology & Embryology	Yes	No
***Figure 8:** Clinical and radiographic images taken from a case reported by Shah *et al*.	31	Shah PN, Arora A V., Kapoor S V. Accessory branch of canalis sinuosus mimicking external root resorption: A diagnostic dilemma. J Conserv Dent. 2017;20(6):479–81.	2018 Journal of Conservative Dentistry	Yes	No

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Appendices

Appendix A: Data collection sheets

Data collection sheet for investigators:

Data Collection Sheet for CS and its AC Including Demographics																	
File number	Sex	Population group	Age	Presence of CS (Yes or No)	Sidedness of CS (Bilateral or Unilateral)	Diameter of CS (mm)	Presence of AC (Yes or No)	Sidedness of AC (Bilateral or Unilateral)	Number of AC			Diameter of AC (mm)		Point of Termination of AC		Course of AC	
									Left	Right	Total	Left	Right	Left	Right	Left	Right

Blinded data collection sheet for external persons:

Data Collection Sheet for CS and its AC Including Demographics																	
Sample number	Sex	Population group	Age	Presence of CS (Yes or No)	Sidedness of CS (Bilateral or Unilateral)	Diameter of CS (mm)	Presence of AC (Yes or No)	Sidedness of AC (Bilateral or Unilateral)	Number of AC			Diameter of AC (mm)		Point of Termination of AC		Course of AC	
									Left	Right	Total	Left	Right	Left	Right	Left	Right

Appendix B: Rescom letter of approval

Chairperson:
Prof RAG Khammissa
Secretary:
Ms Renata van Aswegen

RESCOM

School of Dentistry
Faculty of Health Sciences

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21 July 2021

Prof SL Shangase
CEO/Chair of School
University of Pretoria Oral Health Centre

Dear Prof Shangase,

PROTOCOL APPROVAL: 2021/17

Name: Michael Beckenstrater

Title: A CBCT Study of Canalis Sinuosus and its Accessory Canals in Patients Attending a South African Dental Hospital

The protocol attached hereto was evaluated by two reviewers at the School of Dentistry. After the reviewing process was completed, the Research Committee recommended the approval of the title and the protocol.

Yours sincerely

PROF RAG KHAMMISSA
CHAIRPERSON: RESCOM

Protocol supported / ~~not supported~~

PROF SL SHANGASE
CEO/CHAIR OF SCHOOL
26/07/2021

Appendix C: Ethical clearance

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences

Institution: The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 22 May 2002 and Expires 03/20/2022.
- IORG #: IORG0001762 OMB No. 0990-0279 Approved for use through February 28, 2022 and Expires: 03/04/2023.

Faculty of Health Sciences **Research Ethics Committee**

12 August 2021

Approval Certificate
New Application

Dear Mr MA Beckenstrater

Ethics Reference No.: 428/2021
Title: A CBCT Study of Canalis Sinuosus and its Accessory Canals in Patients Attending a South African Dental Hospital

The **New Application** as supported by documents received between 2021-07-30 and 2021-08-11 for your research, was approved by the Faculty of Health Sciences Research Ethics Committee on 2021-08-11 as resolved by its quorate meeting.

Please note the following about your ethics approval:

- Ethics Approval is valid for 1 year and needs to be renewed annually by 2022-08-12.
- Please remember to use your protocol number (428/2021) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.

Ethics approval is subject to the following:

- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

On behalf of the FHS REC, Professor Werdie (CW) Van Staden
MBChB, MMed(Psych), MD, FCPsych(SA), FTCL, UPLM
***Chairperson**: Faculty of Health Sciences Research Ethics Committee*

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health)

Research Ethics Committee
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Fakulteit Gesondheidswetenskappe
Lefapha la Disaense tša Maphelo

Appendix D: Declaration of Helsinki

All Researchers

Please note that all researchers must from today, sign the attached declaration, when handing in a protocol at the Faculty of Health Sciences Research Ethics Committee - University of Pretoria.

WORLD ASSOCIATION DECLARATION OF HELSINKI
Ethical Principles
For
Medical Research Involving Human Subjects

Adopted by the 18th WMA General Assembly
Helsinki, Finland, June 1964
And amended by the
29th WMA General Assembly, Tokyo, Japan, October 1975
35th WMA General Assembly, Venice, Italy, October 1983
41st WMA General Assembly, Hong Kong, September 1989
48th WMA General Assembly, Somerset West, Republic of South Africa, October 1996
and the
52nd WMA General Assembly, Edinburgh, Scotland, October 2000

A. INTRODUCTION

1. The World Medical Association has developed the Declaration of Helsinki as a statement of ethical principle to provide guidance to physicians and other participants in medical research involving human subjects. Medical research involving human subjects includes research on identifiable human material or identifiable data.

2. It is the duty of the physician to promote and safeguard the health of the people. The physician's knowledge and conscience are dedicated to the fulfilment of this duty.

3. The Declaration of the Geneva of the World Medical Association binds the physician with the words, "The health of my patient will be my first consideration," and the International Code Medical Ethics declares that, "A physician shall act only in the patient's interest when providing medical care which might have the effect of weakening the physical and mental condition of the patient."

4. Medical progress is based on research which ultimately must rest in part on experimentation involving human subjects.

5. In medical research on human subjects, considerations related to the wellbeing of the human subject should take precedence over the interests of science and society.

6. The primary purpose of the medical research involving human subjects is to improve prophylactic, diagnostic and therapeutic procedures and the understanding of the aetiology and pathogenesis of disease. Even the best proven prophylactic, diagnostic and therapeutic methods must continuously be challenged through research for their effectiveness, efficiency, accessibility and quality.

7. In the current medical practice and in medical research, most prophylactic, diagnostic and therapeutic procedures involve risks and burdens.

RESCOM/HELSINKI DECLARATION

8. Medical research is subject to ethics standards that promote respect for all human beings and protect their health and rights. Some research population is vulnerable and need special protection. The particular needs of the economically and medically advantaged must be recognized. Special attention is also required for those who cannot give us or refuse consent for themselves, for those who may be subject to giving consent under duress, for those who will not benefit personally from the research and for those for whom the research is combined with care.

9. Research investigators should be aware of the ethical, legal and regulatory requirements for research on human subjects in their own countries as well as applicable international requirements. No national ethical, legal and regulatory requirements should be allowed to reduce or eliminate any of the protections for human subjects set forth in this Declaration.

B. BASIC PRINCIPLES FOR ALL MEDICAL RESEARCH

10. It is the duty of the physician in medical research to protect the life, health, privacy and dignity of the human subject.

11. Medical research involving human subject must conform to the general accepted scientific principles, be based on the thorough knowledge of the scientific literature, other relevant sources of information, and on adequate laboratory and, where appropriate, animal experimentation.

12. Appropriate caution must be exercised in the conduct of research which may affect the environment, and the welfare of animal used for research must be respected.

13. The design and performance of each experimental procedure involving human subjects should be clearly formulated in an experimental protocol. This protocol should be submitted for consideration, comment, guidance and where appropriate, approval to a specially appointed ethical review committee, which must be independent of the investigator, the sponsor or any other kind of undue influence. This independent committee should be in conformity with the laws and regulations of the country in which the research experiment is performed. The committee has the right to monitor ongoing trials. The researcher has the obligation to provide monitoring information to the committee, especially any serious adverse events. The researcher should also submit to the committee, for review, information regarding funding, sponsors, institutional affiliations, other potential conflicts of interest and incentives for subjects.

14. The research protocol should always contain a statement of the ethical considerations involved and should indicate that there is compliance with the principles enunciated in this Declaration.

15. Medical human research involving subjects should be conducted only by scientifically qualified persons and under the supervision of a clinically competent medical person. The responsibility for the human subject must always rest with a medically qualified person and never rest on the subject of the research, even though the subject has given consent.

16. Every medical research project involving human subject should be preceded by careful assessment of predictable risk and burdens in comparison with foreseeable benefits of the subject or to others. This does not preclude the participation of healthy volunteers in medical research. The design of all studies should be publicly available.

17. Physicians should abstain from engaging in research project involving human subjects unless they are confident that the risk involved have been adequately assessed and can be satisfactorily managed. Physicians should cease any investigations if the risks are found to outweigh the potential benefits or if there is conclusive proof of positive and beneficial results.

18. Medical research involving human subjects should only be conducted if the importance of the objective outweighs the inherent risks and burdens of the subject. This is especially important when the human subjects are healthy volunteers.

RESCOM/HELSINKI DECLARATION

C. ICH GUIDELINE FOR GOOD CLINICAL PRACTICE

1. Clinical trials should be conducted in accordance with the ethical principles that have their origin in Declaration of Helsinki, and that are consistent with GCP and the applicable regulatory requirement(s).

2. Before a trial is initiated, foreseeable risk and inconvenience should be outweighed against the anticipated benefit for the individual trial subject and society. A trial should be initiated and continued if the anticipated benefits justify the risk.

3. The rights, safety and well being of the trial subjects are the most important considerations and should prevail over interest of science and society.

4. The available non-clinical and clinical information on an investigational product should be adequate to support the proposed clinical trials.

5. Clinical trials should be scientifically sound, and described in a clear, detailed protocol.

6. A trial should be conducted in compliance with the protocol that has received prior institutional review board (IRB)/independent ethics committee (IEC) approval/favourable opinion.

7. The medical care given to, and medical decisions made on behalf of, subjects should always be the responsibility of the qualified physician or, when appropriate, of a qualified dentist.

8. Each individual involved in conducting a trial should be qualified by education, training, and experience to perform his or her respective task(s).

9. Freely given informed consent should be obtained from every subject prior to clinical trial participant.

10. All clinical trial information should be recorded, handled and stored in a way that allows its accurate reporting, interpretation and verification.

11. The confidentiality of records that could identify subjects should be protected, respecting the privacy and confidentiality rules in accordance with the applicable regulatory requirement(s).

12. Investigational product should be manufactured, handled, and stored in accordance with applicable good manufacturing practice (GMP). They should be used in accordance with the approved protocol.

13. Systems with procedures that assure the quality of every aspect of the trial should be implemented.

Appendix E: Biostatistician clearance

This letter is to confirm that the student,

with the Name

Michael Beckenstrater (16070276),

studying at the University of Pretoria discussed the Project with the title:

"A CBCT Study of Canalis Sinuosus and its Accessory Canals in Patients Attending a South African Dental Hospital"
with me.

I hereby confirm that I am aware of the project and also undertake to assist with the Statistical analysis of the data generated from the project.

The analytical tools that will be used will be used are: the calculation and analysis of frequency distributions, mean and median values using SAS (SAS Institute Inc, Carey, NC, USA)

to achieve the objective(s) of the study.

Name: Prof H S Schoeman

Date: 19 May 2021

Signature:

Tel: 082 896 3606

Department: Biostatistician for ClinStat CC

ClinStat CC
CK 96/35541/23
082 896 3606